

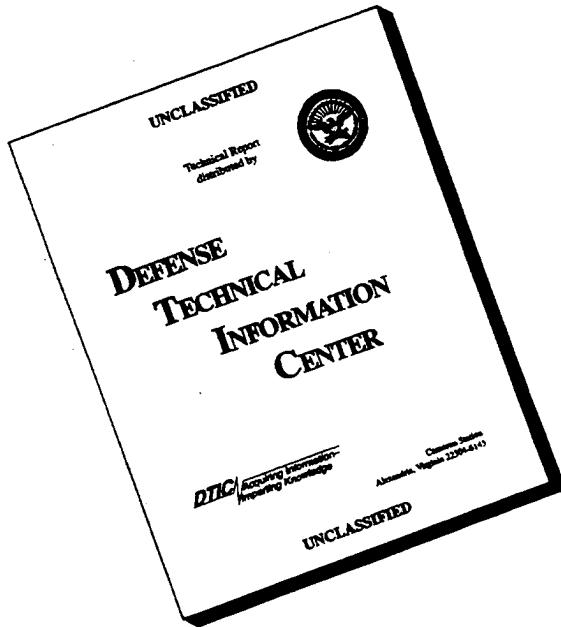
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COMMON INSTRUCTIONAL INTERACTION STRATEGIES AND THEIR
EFFECTS ON THE CONSTRUCTION OF FRAGILE KNOWLEDGE IN FLIGHT

SIMULATION

by

Major Michael William Mullas, USAF

B.S., Embry-Riddle Aeronautical University, 1982

M.S.A., Central Michigan University, 1988

A thesis submitted to the

University of Colorado at Denver

in partial fulfillment

of the requirements for the degree of

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Mullas, Michael William (Ph.D., Educational Leadership and Innovation)

Common Instructional Interaction Strategies and Their Effects on the Construction of Fragile Knowledge in Flight Simulation (112 pages).

Thesis directed by Associate Professor R. Scott Grabinger

ABSTRACT

The construction of fragile knowledge hinders the learning process- in some cases it can produce tragic consequences. This study examined the effects of common instructional interaction strategies on fragile knowledge construction in learners during procedural skill acquisition. It also examined whether explicit instruction on executive control strategies can eliminate or minimize fragile knowledge construction.

The experimental design was a 4 X 2 factorial pretest, posttest, control group design. The two independent variables were instructional interaction strategies and executive controls. There were four levels of interaction strategies: no instructional interaction (the control group), directive interaction, question-based interaction, and mixed (directive and question-based) interaction. There were two levels of executive controls: no instruction on executive control processes and explicit instruction on executive control processes.

One hundred forty-seven undergraduate students received eight hours of classroom instruction on basic air navigation, a pretest, two 2-hour simulator missions (instructed according to their particular treatment group), and a posttest.

An ANCOVA compared posttest scores with pretest scores as the covariate to examine them for main effects or interaction. A MANCOVA was performed to determine whether certain interaction strategies produced particular types of fragile knowledge. Results showed that the mixed interaction strategy exhibited a one standard deviation advantage over all other strategies in reducing fragile knowledge construction. However, there were no significant differences for executive control processes or types of fragile knowledge construction.

There are several implications: first, use a mixed interaction strategy that begins with a directive approach and changes to a questioning style while the learner performs the procedural task; second, avoid using a entirely directive or questioning approach; finally, use questioning strategies that focus on where we get information, how we process information, and what we do with the results.

This abstract accurately reflects the content of the candidate's thesis. I recommend its publication.

Signed _____
R. Scott Grabinger

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This Thesis for the Doctor of Philosophy

degree by

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25 April 1996
Date

DEDICATION

To the men and women who educate and train tomorrow's air and space leaders

and

To my wife Karen who is educating and training four of tomorrow's air and space leaders: Emily, Beth, Amy, and Jenna

One hundred forty-seven undergraduate students received eight hours of classroom instruction on basic air navigation, a pretest, two 2-hour simulator missions (instructed according to their particular treatment group), and a posttest.

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Signed 
R. Scott Grabinger

Mullas, Michael William (Ph.D., Educational Leadership and Innovation)

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Fragile Knowledge in Flight Simulation**

Thesis directed by Associate Professor R. Scott Grabinger

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CHAPTER 1

STATEMENT OF THE PROBLEM

Introduction

A student pilot departs on a solo cross-country flight. The primary gyro compass fails half way through the flight leaving the pilot with only the standby magnetic compass for directional reference. The novice pilot remembers to correct the readings for the deviation of the instrument, but does not correct for difference between the earth's magnetic and north poles and quickly becomes seriously disoriented. Ultimately, disorientation and low fuel produce catastrophic consequences.

In another incident, a motorist in a borrowed car on an icy road begins to skid. Almost instinctively, the driver steers into the skid in an attempt to correct the condition as he would have done in his own car. Unfortunately, the driver owns a rear wheel drive vehicle, and the borrowed vehicle is a front wheel drive. The skid becomes aggravated, and the car slides across the median totally out of control.

What do these two incidents have in common? Both cases are instances of fragile knowledge. In the first case, the novice pilot is missing critical knowledge. In the second case, the driver inappropriately applied knowledge from one situation to an entirely different situation. What is fragile knowledge?

Definition of Fragile Knowledge

According to David Perkins (1992, p. 20) fragile knowledge is knowledge that a person “does not remember, understand, or actively use much of what they have supposedly learned.” This type of knowledge has little substance or strength and is flimsy or weak when demands are made on it. Research shows that fragile knowledge can manifest itself in several forms. The six most common types of fragile knowledge are:

- inert knowledge (Whitehead, 1929)
- partial or missing knowledge (Perkins & Martin, 1985, p. 5)
- misplaced knowledge (Perkins & Martin, 1985, p. 5)
- naive knowledge (Perkins & Martin, 1985, p. 5)
- conglomerative knowledge (Perkins & Martin, 1985, p. 5)
- ritual knowledge (Taba & Elzey, 1964, p. 524)

Perkins (1992) claims that these six types of fragile knowledge can combine in a learner causing the display of a distinctive cluster of behaviors. This distinctive cluster of behaviors has been labeled fragile knowledge syndrome. The following example from Perkins (1992) illustrates this syndrome.

Brian is tackling fraction computation problems. For the simplest problems, Brian proceeds nicely. Encountering a mixed number, Brian has no idea what to do with it--a knowledge gap. On another problem, Brian obtains an answer that needs reducing but forgets to reduce it, even though he knows how. On an addition problem, Brian cancels a 3 in the numerator of one term against a 3 in the

denominator of the other, mistakenly believing that cancellation works for sums as well as products. However, on a similar problem, he does not try canceling and solves the problem correctly. (p. 26)

The performance in this example is inconsistent. At times, the learner seems competent. However, at other times, with similar problems the learner reaches an impasse or elects to perform an inappropriate action. The cause of the impasses or inappropriate actions can be traced to one of several common types of fragile knowledge.

To provide a little more detail on the types of fragile knowledge, “inert knowledge refers to situations where the student fails to retrieve knowledge but in fact possesses it, as revealed by a clinical probe” (Perkins & Martin, 1985, p. 5). Partial knowledge “is the straightforward case of an impasse due to knowledge the student has not retained or ever learned, as revealed by clinical probes failing to reveal signs of the knowledge” (Perkins & Martin, 1985, p. 5). Misplaced knowledge is an instance of a student importing knowledge appropriate to one context but inappropriate to the new context. Naive knowledge is knowledge that takes the form of naive theories and stereotypes (Perkins, 1985, p. 5). A “flat earth” is a common example of this type of knowledge. Conglomerative knowledge signifies an attempt by the student to force together disparate elements of knowledge to provide a solution to a problem, repair a bug, or resolve an impasse. Finally, ritual knowledge is knowledge that is culturally defined and usually limited to a particular

context; for example, knowledge or tasks that are useful in school but not anywhere else.

Educators have an ethical responsibility to minimize the construction of fragile knowledge. Are there things that we can do as educational professionals to minimize or inhibit the learners' construction of fragile knowledge? Does how we interact with learners in an instructional context influence what they learn? Do instructional interaction strategies that we use with students influence what they learn? If the answer is yes, then are some strategies more effective than others in minimizing or inhibiting particular types of fragile knowledge construction? We have a responsibility to our clients and students to seek answers to these questions.

Purpose of the Study

This study examined the effects of four common instructional interaction strategies and their effects on the learners' construction of fragile knowledge during initial procedural skill acquisition. The study also examined the effect of providing explicit instruction on executive control processes and strategies during initial procedural skill acquisition. Executive control processes are those processes involved in planning, monitoring, and evaluating performance on intellectual tasks (Vygotsky, 1978).

This research effort addressed the following questions: Does the way we interact with learners have an effect on the learners' construction of fragile

knowledge? If so, are some interaction strategies more effective than others at minimizing or inhibiting the construction of particular types of fragile knowledge?

Also, previous research has suggested that direct instruction on executive control processes may reduce fragile knowledge construction in problem-based learning environments (Perkins & Martin, 1985). Can direct instruction on executive control processes reduce fragile knowledge construction during acquisition of algorithmic-heuristic cognitive skills?

Finally, is there an interaction between the use of common instructional interaction strategies and the explicit instruction of executive control processes? Are there certain combinations of interaction strategies and executive control processes that together produce a significant difference in the amount of fragile knowledge construction?

Experimental Intervention

The design of this experiment was a 4 X 2 factorial design. The two independent variables were instructional interaction strategies (with four levels) and executive control strategies (with two levels).

The combination of levels of the two independent variables resulted in eight treatments being administered in this experiment. The eight treatments were:

1. No instructional interaction with executive controls: Subjects in this treatment group were given a coursebook which contained the information necessary

to complete the specific procedures addressed by each particular learning objective.

After receiving a coursebook, the subjects were sent to the simulator to complete the simulation without any instructional assistance. Their coursebook contained explicit instruction on executive control strategies applicable to each procedure they were required to perform.

2. No instructional interaction without executive controls: These subjects were given a coursebook and sent to the simulator to complete the lesson without any instructional assistance. Their coursebook did not contain any instruction on executive control strategies.

3. Directive/didactic instructional interaction with executive controls:

Instructors in this group directed subjects through each procedure. Each subject was told in a direct step-by-step manner how to accomplish each of the required tasks.

The instructional interaction strategy focused on “telling” or making directive or declarative statements to the learner to perform each step of the procedure.

Instructors in this group also provided explicit (but still directive) instruction on executive control of the processes within the procedures.

4. Directive/didactic instructional interaction without executive controls:

Subjects in this group received the same type of interaction as the previous group, but they did not receive any instruction on executive control of the processes within the procedures.

5. Questioning/Reflective instructional interaction with executive controls:

Instructors in this group used questions to guide students through the same tasks as the other groups. They also used questions to lead the student through executive control strategies that could be used to resolve impasses or check the output of the procedures being performed.

6. Questioning/Reflective instructional interaction without executive

controls: This group experienced the same interaction style as the previous group, but it did not receive the additional questioning on executive control strategies.

7. Mixed Directive/Reflective instructional interaction with executive

controls: Instructors in this group presented the procedures in a directive style first, and then they shifted to a questioning strategy as the subject performed the skill. Subjects in the other instructor-assisted groups were simply directed through the procedure a second time to ensure equal time-on-task for all treatment groups.

Subjects in this group also received explicit instruction (in a questioning type interaction style) on executive control strategies.

8. Mixed Directive/Reflective instructional interaction without executive

controls: Subjects in this group received the same style of interaction as the previous group, but they didn't receive any instruction on executive control strategies.

All eight treatments were conducted within the context of two actual navigation simulation missions. These missions were part of a current course on

navigation taught at the United States Air Force Academy. The subjects were taking their first air navigation course. Each subject received: (1) a pretest, (2) two navigation simulation missions with instruction according to their treatment group, (3) and an immediate posttest. The posttest measured how much fragile knowledge on basic air navigation principles and procedures the subject still possessed after the instructional treatment. The number of instances of fragile knowledge of basic air navigation principles and procedures was the dependent variable in this study.

Research Hypotheses

The primary hypothesis stated that subjects who were provided instructional interaction would perform better on the posttest than subjects who were not provided instructional interaction. Better performance (higher scores) on the posttest indicated less fragile knowledge construction. The reason for this is that expert guidance during the knowledge compilation process in the associative stage of cognitive skill development should have an effect on what the learner encodes. Including input from experts should clarify what actually gets encoded during the compilation process, thus strengthening the semantic connections the learner makes. Strengthening the semantic connections should reduce the likelihood of constructing a tenuous grasp on the knowledge.

A secondary hypothesis stated that subjects who were provided explicit instruction on executive control processes would score better on the posttest than

subjects who weren't provided this instruction. Once again, a better score on the posttest indicated a lower amount of fragile knowledge present in the learner. The reason for this hypothesis is that the possession and use of executive control strategies should enable learners to solve their own impasses and gain a stronger grasp on the knowledge to be gained. Subjects who were unable to resolve their own impasses would not even have access to the additional knowledge opportunities that existed beyond the initial point of their impasse.

Significance of the Study

This study provided evidence for educational professionals concerning the issue of the influence of common instructional interaction strategies on their ability to reduce, minimize, or inhibit the learners' construction of fragile knowledge during initial procedural skill acquisition. Knowing whether these strategies have an effect on knowledge construction or which strategies are more effective than others in reducing the construction of fragile knowledge will enable educational professionals to make improvements to products and processes that will reduce the construction of fragile knowledge and its consequences.

Definition of Terms

Cognitive Strategies: "skills by which learners regulate their own internal processes of attending, learning, remembering, and thinking" (Gagné, 1985, p. 55).

Conglomerative Knowledge: signifies an attempt by the student to force together disparate elements of knowledge to provide a solution to a problem, repair a bug, or resolve an impasse (Perkins and Martin, 1985, p. 7).

Executive Control Processes: are “those processes involved in planning, monitoring, and evaluating performance on intellectual tasks” (Sincoff & Sternberg, 1989, p. 33).

Executive Control Strategies: are a superset of cognitive strategies. According to Robert M. Gagné (1985, p. 77) “they are a part of the information-processing theory of learning and memory that influences attention and selective perception which determine what is encoded into short and ultimately long-term memory.” The executive control strategies used in this study included additional procedural tools that were used to control and cross-check the execution of the navigation procedure. These strategies included: close tracking of the procedure being executed, strategic orientation, and self-prompting.

Fragile Knowledge: David Perkins (1985, p. 5) defines fragile knowledge as knowledge that “students do not remember, understand, or use actively much of what they have supposedly learned; and poor thinking, which means that students do

not think very well with what they know.” This type of knowledge has little substance or strength and is flimsy or weak when demands are put on it.

Inert Knowledge: refers to “situations where the student fails to retrieve knowledge but in fact possesses it, as revealed by a clinical probe” (Perkins, 1985, p. 5).

Instructional Interaction Strategy: a superset of elemental methods or tactics for conveying instruction to the learner and/or for receiving and responding to input from the learner. Instructional interaction strategies are similar to instructional delivery strategies, but they focus exclusively on the instructor/learner exchange. Some typical strategies include directive or didactic strategies, questioning or reflective strategies, or combinations of the two.

Misplaced Knowledge: is an instance of a student importing knowledge appropriate to another context but inappropriate to the context it is being imported to.

Naive Knowledge: is knowledge that takes the form of naive theories and stereotypes (Perkins, 1985, p. 5). A “flat earth” is a common example of this type of knowledge.

Partial Knowledge: “is the straightforward case of an impasse due to knowledge the student has not retained or ever learned, as revealed by clinical probes failing to reveal signs of the knowledge” (Perkins, 1985, p. 5).

Ritual Knowledge: is knowledge that is culturally defined and usually limited to a particular context; for example, knowledge or tasks that are useful in school but not anywhere else (Taba & Elzey, 1964).

CHAPTER 2

REVIEW OF LITERATURE

Introduction

The concept and consequences of fragile knowledge are not new. However, systematic research of fragile knowledge is limited in scope and dates back only ten years. What insights into the nature of fragile knowledge do we currently possess? We must assess the current state of our knowledge before finding and developing new techniques to minimize construction of fragile knowledge and reduce our exposure to its consequences.

This chapter surveys the literature on fragile knowledge and examines the broader domain of procedural skill acquisition. It starts with the theoretical limitations of the scope of the survey of the literature, and then it briefly delineates the philosophical assumptions of the study. With the theoretical foundation of the review set, it begins by examining the definition of fragile knowledge, and then it seeks to define cognitive skill. Once the concept of cognitive skill is defined, the focus then shifts to the acquisition of cognitive skill and to the origins and development of procedural skill. The theoretical portion of the review concludes with an examination of executive control processes and how they can effect the procedural

skill acquisition process. Finally, literature on common instructional interaction strategies concludes the chapter, establishes the theoretical rationale for the study, and provides the connection to previous research on the topic of fragile knowledge and its effects on learners.

Theoretical Limitations

Fragile knowledge is a broad concept with an infinite number of possible contexts. This review is limited to literature pertaining to fragile knowledge construction during initial algorithmic-heuristic procedural skill acquisition as defined by Colley and Beech (1989). Algorithmic-heuristic procedural skills are a set sequence of steps a performer uses to arrive at a solution (Colley & Beech, 1989). Only the cognitive domain is addressed; the affective and psychomotor domains are not reviewed. Furthermore, issues of transfer and retention of procedural skills are also ignored. This is not to imply that the domains or issues not covered are not important; they are simply not of interest to this particular study. This study focuses on the construction of fragile knowledge at the point of initial cognitive procedural skill acquisition.

Philosophical Assumptions

In another effort to stabilize the theoretical foundation, an information processing model (Gagné, 1974, 1985) was assumed throughout this study. The information processing model was chosen because of its broad representation in the

literature on procedural skill acquisition (Anderson, 1980). Furthermore, information processing models address the process of skill acquisition which is the focus of this study. Although the information processing model cannot completely explain the complexities and intricacies associated with more holistic views on learning, the model does provide a practical means to communicate observations of a complex phenomenon such as cognitive procedural skill acquisition between researchers and consumers of research.

Information-processing theory grew out of human factors work and information theory; it gained prominence during the reemergence of cognitive psychology after World War II (Anderson, 1980). Newell and Simon's work during the 1960s and 1970s on artificial intelligence at Carnegie-Mellon has also strongly influenced the information-processing model.

Information processing approaches to explaining human cognition center around the analogy between how a computer is programmed to process information and how a human processes information. Cognitive psychologists who hold this view see the human mind as a computer (Andre & Phye, 1986). "Information-processing models suggest that people 'store' concepts and rules in a place called memory through a vast network or schema of interrelated symbols, propositions, and knowledge components" (Wilson & Teslow, 1992, p. 1). According to John Anderson (1980, p. 13),

there is a clear sequence or serial ordering to mental operations, and the important characteristic of an information-processing analysis, then, is that it involves a tracing of a sequence of mental operations and their products (information) in the performance of a particular cognitive task

By this statement, Anderson asserts that there is a sequence of mental operations that convert raw sensory information into knowledge. Do changes in the mental operations in this sequence produce corresponding changes in the information that is converted into knowledge? If so, can these variations in information processing produce fragile knowledge?

Definition of Fragile Knowledge

The first and most obvious question is what is fragile knowledge? Fragile knowledge is knowledge that “students do not remember, understand, or use actively much of what they have supposedly learned; and poor thinking, which means that students do not think very well with what they know” (Perkins, 1992, p. 20).

Research shows that fragile knowledge can manifest itself in several forms; however, these various forms can also combine in a learner which results in the display of a distinctive cluster of behaviors called fragile knowledge syndrome (Perkins, 1992, p. 26). Several common forms of fragile knowledge are:

- inert knowledge (Whitehead, 1929)
- partial or missing knowledge (Perkins & Martin, 1985, p. 5)
- misplaced knowledge (Perkins & Martin, 1985, p. 5)

- naive knowledge (Perkins & Martin, 1985, p. 5)
- conglomerative knowledge (Perkins & Martin, 1985, p. 5)
- ritual knowledge (Taba & Elzey, 1964, p. 524)

To provide a little more detail, “inert knowledge refers to situations where the student fails to retrieve knowledge but in fact possesses it, as revealed by a clinical probe” (Perkins, 1985, p. 5). In aviation, an important ability that every pilot must possess is the ability to determine when the aircraft will arrive at a specific geographic point. Estimating the time of arrival accurately facilitates smooth coordination with ground support personnel and enables accurate monitoring of fuel requirements for the flight. Inability to recall the first step of how to compute an estimated time of arrival (ETA) during the simulation is an example of inert knowledge within the context of this study.

Partial knowledge “is the straightforward case of an impasse due to knowledge the student has not retained or ever learned, as revealed by clinical probes failing to reveal signs of the knowledge” (Perkins, 1985, p. 5). The symptoms of partial knowledge are similar to the symptoms of inert knowledge. The key to distinguishing between the two types is that in the case of inert knowledge probing by the instructor reveals that the student does in fact remember the information. In the case of partial knowledge, probing questions used by the instructor fail to reveal that the student actually possessed the knowledge in the first place.

Misplaced knowledge is an instance of a student importing knowledge appropriate to a particular context but inappropriate to the new context. Attempting to compute a groundspeed for the ETA computation instead of reading it from the Navigation Computer System is an example of misplaced knowledge. Computing a groundspeed is appropriate for flight planning, but it is inappropriate for ETA computation.

Naive knowledge is knowledge that takes the form of naive theories and stereotypes (Perkins, 1985). A “flat earth” is a common example of this type of knowledge. We know that the earth is not flat; it is round. You cannot fly off the end of the earth. Using true airspeed instead of groundspeed for the ETA computation is an indication of the presence of naïve knowledge.

Conglomerative knowledge signifies an attempt by the student to force together disparate elements of knowledge to provide a solution to a problem, repair a bug, or resolve an impasse. Measuring a distance from a dead reckoning position instead of measuring the distance from a navigational fix (as the ETA computation procedure calls for) simply to be able to come up with a possible answer for the ETA problem is indicative of conglomerative knowledge.

Finally, ritual knowledge is knowledge that is culturally defined and usually limited to a particular context; for example, knowledge or tasks that are useful in school but not anywhere else. Teaching students to use a slide rule to perform

mathematical calculations when the “real world” uses electronic calculators is an example of ritual knowledge. All tasks performed in the study were real-world tasks. None of the concepts or procedures were for training purposes only. Therefore, ritual knowledge was not relevant to this study.

All of the concepts mentioned here are manifestations or instances of fragile knowledge. Fragile knowledge, as mentioned previously, is a significant deterrent to the successful performance of any cognitive skill. What is a cognitive skill? How is it acquired? Answers to these questions will yield an insight into the nature of cognitive skills and how to minimize the effects of fragile knowledge during the initial acquisition of a cognitive skill.

Definition of Cognitive Skill

A cognitive skill is the ability to perform an intellectual procedure (Anderson, 1980). Cognitive skill encompasses two categories of knowledge. The first category of knowledge in a cognitive skill is declarative knowledge. Declarative knowledge is “knowing that.” The second category is procedural knowledge. Procedural knowledge is “knowing how (Gagné, 1985, p. 48).” Possessing both categories of knowledge is paramount to the ability to perform a cognitive skill. Now that we know what a cognitive skill is, how is it acquired?

Acquisition of Cognitive Skill

Recent approaches to examining skill acquisition focus on the works of John Anderson from Carnegie-Mellon. According to Colley and Beech (1989), Anderson provides a framework for understanding observations made earlier by Fitts (1964) on the development of skill. Colley and Beech (1989) outline Fitts' three stages of cognitive skill development:

the cognitive stage, in which the learner makes an initial approximation to the skill, based upon background knowledge, observation or instruction; the associative stage, in which performance is refined through the elimination of errors; and the autonomous stage, in which skilled performance is well-established but still continues to improve, albeit very gradually. (p. 7)

Anderson's (1982) adaptive control of thought (ACT) theory posits two stages of skill development. His first stage is the **declarative stage**. In this stage, declarative representations relevant to the skill guide behavior. The second stage is the **procedural stage** where knowledge undergoes a process of conversion and continual refinement of conditions and actions into procedures. He calls the process of converting facts into procedures **knowledge compilation** (Colley and Beech, 1989). Knowledge compilation also results in an increase in the rate of production application (condition-action pairs being applied to solve procedural problems) and tuning processes. This becomes the basis for improving procedural skill performance and facilitating the transition from novice to expert.

In Anderson's declarative stage, knowledge about how to perform a skill is assembled from declarative memory, and from instruction or guidance, into working memory. General problem-solving procedures then turn this declarative knowledge into productions which are composed of condition-action pairs. Rummelhart and Norman (1981) discuss the utility of analogy to create or extend schemata's ability to incorporate task knowledge in procedures. How is declarative knowledge converted into procedural knowledge? It happens through a process called knowledge compilation. Knowledge of the compilation and tuning processes provides a conceptual framework for understanding how and why instructional interaction may have an effect on knowledge construction.

Knowledge compilation occurs between the declarative and procedural stages of cognitive skill acquisition. Knowledge composition has two subprocesses: composition and proceduralization. Composition (Lewis, 1978) collapses successive productions (condition-action pairs) into a single production which has the same effect. Proceduralization removes clauses in the condition of a production that require matching from long-term memory via working memory. This removal of clauses permits automatization of the procedural task. Compilation is a gradual process which allows for errors in procedural information to be corrected over practice.

In the procedural stage of acquisition, productions are tuned, that is, made more appropriate and efficient for the task at hand. Tuning has three subprocesses: generalization, discrimination, and strengthening. Generalization occurs when common aspects of specific productions are used to create a more widely applicable production which can be used in novel situations. Discrimination restricts the use of productions to instances where they are successful. Strengthening involves repeating applications so that the time taken to apply them diminishes (Colley & Beech, 1989). Now that we understand the cognitive skill acquisition process, it's time to look at the procedural skill acquisition process.

Origins and Development of Procedural Skill

With the broader context of cognitive skills established, the focus now narrows to procedural skills which are a subset of cognitive skill. Although some controversy and a few alternative theories exist, Anderson's (1982) adaptive control of thought (ACT) theory remains the seminal work on procedural skill acquisition. The controversy centers around Anderson's claim that knowledge must be encoded declaratively before proceduralization can occur and that proceduralization can only occur as a by product of actually performing the procedure. Kieras and Bovair (1985) disagree. Their study claims that learners can represent production rules (the If (condition) THEN (action) statements) declaratively before they are proceduralized without having to actually perform the procedure. In spite of the

disagreement on when a production can be proceduralized there is agreement on what actually happens in the process.

According to ACT theory (Anderson, 1982) the procedural skill acquisition process involves three distinct steps. These steps are encoding, proceduralization, and composition (Neves & Anderson, 1981). All incoming knowledge is encoded declaratively as a set of facts in a semantic network. This information is then proceduralized by converting it into productions which are condition-action pairs. These productions created during the proceduralization phase are then subject to the composition process. During the composition process productions are combined into larger productions to decrease the amount of time required to apply a procedure.

Anderson (1981, p. 67) provides the following illustration of composition:

Production 12: If you see a red light
 Then assert danger.

Production 13: If there is danger and another person is near you
 Then warn that person.

The simple composite is:

Production 14: If you see a red light
 and there is danger
 and another person is near you
 Then assert danger
 and warn that person

However, this process is not without its problems. Problems that result in bugs or impasses can occur at any point during the acquisition process. Burton and Brown (1982) conducted extensive research on this subject with their classic program Debuggy. Bugs are systematic errors in the execution of procedural skills, and these errors produce fragile knowledge. Burton and Brown (1982), VanLehn (1982), Shaw (1982), and Sleeman (1984) observed and documented over 200 different kinds of bugs in the acquisition of simple mathematical skills alone. Bugs indicate the presence of fragile knowledge in the learner.

VanLehn (1982) claims that mysteries abound in bug data and looks to answers to the following questions as central to solving these mysteries.

Why are there so many different bugs? What causes them?
What causes bugs to migrate or disappear? Why do certain bugs only migrate to certain other bugs? Often a student has more than one bug at a time---why do certain bugs almost always occur together?
Do co-occurring bugs have the same cause? Most important, how is the educational process involved in the development of bugs? (p. 49)

VanLehn appears to believe that a correlation may exist between the educational process and the development of bugs that produce fragile knowledge. Since bugs indicate the presence of fragile knowledge in the learner, can the educational process eliminate or reduce these bugs? Are there things educators can do to facilitate bug-free procedural skill learning?

Executive Control Processes

Much of VanLehn's work focuses on impasses caused by bugs and points to executive control processes to solve these impasses and repair the bugs that caused them. Executive control processes facilitate the planning, monitoring, and evaluating of performance on intellectual tasks (Vygotsky, 1978).

Case (1984, 1985) argues that the learner's ability to assemble increasingly sophisticated executive control structures underlies most of their cognitive change. According to Case, executive control structures consist of three interrelated parts: a representation of the problem situation, a representation of the problem objective, and a representation of the problem strategy. This tells us what the structure of our interaction with the learner must contain to be considered an executive control.

Sternberg (1984, 1985) further refines the executive control process. He identifies nine types of metacomponential processing that fulfill executive processing functions. Metacomponential processes are subprocesses of a procedural skill much like cognitive strategies that help regulate the execution of the procedure. Nine types of metacomponential processing account for many of the consistent findings across the literature on cognitive development. He contends that a learner accomplishing an intellectual task must:

- Determine the nature of the problem under consideration
- Select the appropriate performance components for solving the problem
- Select a strategy for combining performance components in an optimal way

- Select one or more representations for the information crucial to problem solution
- Decide how to allocate processing resources
- Monitor their performance
- Interpret feedback about the effectiveness of their efforts
- Decide how to act upon positive or negative feedback
- Modify their performance in response to the feedback

Now that we know exactly what the elements of an effective executive control strategy are. These elements must be incorporated into our instructional interaction with the learner if our objective is to provide effective executive control strategies.

Since studies have shown executive control processes to be effective for repairing bugs (Burton & Brown, 1982; VanLehn, 1982), can they also provide clues to solving the problems associated with the construction of fragile knowledge? Referring back to VanLehn's most important issue earlier, "how is the educational process involved in the development of bugs?" Research on teacher behavior sheds some light on the issue.

Teacher Behavior and Student Achievement

Jere Brophy (1979) conducted extensive research on teacher behavior and its effects on student achievement to show a significant correlation between teacher behavior and student achievement. Brophy also exposes gaps in the literature and research methodology. One of the significant gaps is research on the effectiveness of questioning techniques on student achievement. A synthesis of findings over several studies indicates that factual questions with single answers was correlated positively

and significantly with achievement, whereas the frequency of more complex, difficult, or divergent questions had negative correlations (Brophy, 1979). The lack of significant results for complex or higher level questions has puzzled researchers and caused them to conclude that we need to rethink what is meant by types of questions and their effects. Rosenshine (1976) summarized the findings of several studies on teaching behaviors and student achievement conducted during the 1970's by stating that "we are as yet unaware of the optimal types and sequencing of questions...optimal sequences may be different for different types of students and outcomes, but we still do not know what these sequences are" (p. 61). Meredith Gall's work at the Far West Laboratory for Educational Research and Development supports Brophy's claims. Gall (undated, p. 707) says that

Granting the importance of questions in teaching, researchers still do not know much about them. What educational objectives can questions help students achieve? What are the criteria of an effective question and how can effective questions be identified? Until researchers find answers to questions such as these, a viable behavioral technology of teaching will remain unrealized.

Gall (undated, p. 707) goes on to say that "very few researchers have explored the relationship between teacher's questions and student outcomes."

Rosenshine (1976, p. 61) confirms this by stating that "Since 1940 fewer than 25 studies have been conducted on any specific variable such as teacher praise or teacher questions." More recent research is equally as sparse. The basic

conclusion here is that researchers agree that the issue is important, but little research is actually being conducted in this area. Brophy and Gall support the need for more research on teacher questions. While the need for this research is apparent, research on the use of questioning as an instructional strategy is also needed.

Instructional Interaction Strategies

Instructional interaction strategies were previously defined in Chapter 1. Common instructional interaction strategies are addressed in the Minnesota Department of Education's publication entitled "Classroom Instructional Design: Options for Teacher/Student Interaction" (1989). This publication details three common teaching models for teacher/student interaction. These interaction strategies are: directive, investigative, and interactive. The directive strategy involves "telling" to present content. The investigative strategy involves a questioning approach to achieving the lesson objective, and the interactive strategy is a mixture of both telling and questioning.

Perkins (1992) hails Mortimer Adler's (1980) paidea proposal as a solution to fragile knowledge syndrome. Adler proposes an interaction strategy that involves didactic instruction followed by coaching and Socratic approaches to presenting instruction. Here, the didactic approach corresponds to the directive approach from the Minnesota group. Adler's coaching phase corresponds to the interactive stage,

and the Socratic approach corresponds to the investigative strategy mentioned earlier.

In the directive approach to interaction, the instructor or intelligent tutoring system is the possessor of knowledge. This knowledge is presented to the learner by "telling" or making declarative statements to explicitly direct the learner through the instructional activities to achieve the learning objectives and goals. These learning objectives could be a complex process or procedure. The following example, which is the actual procedure to compute an estimated time of arrival (ETA) at a predetermined geographic point, illustrates the directive interaction strategy in a typical instructional scenario:

Instructor: "It's time to compute an ETA. The first thing you need to do to compute an ETA is to get the aircraft's groundspeed from the Navigation Computer System. Then, take your plotter and measure from the fix you resolved and plotted on your chart to the geographic point that you would like to compute the ETA to. Now, divide the distance you measured with your plotter by the groundspeed. The result is how long it will take to fly the distance you measured. Add this time to the time of your fix and you now have your estimated time of arrival."

At this point in the scenario the instructor would then repeat the same instruction once again as the student performed the task.

In the questioning approach to interaction, questions are used to lead the learner through the accomplishment of the process. Making declarative statements to

the learners is not part of this interaction strategy. The questioning approach should not be confused with inquiry teaching, because in this case, what is to be learned is a previously established process that has a correct sequence for accomplishment and consequences for incorrect sequences. Learners are not encouraged to invent their own sequences or cases and test their hypotheses. Again the same task is used to illustrate the questioning approach:

Instructor: "What do we need to do right now?"
Student: "We need to compute an ETA to our destination."
Instructor: "How do we do that?"
Student: "First, we need to get the aircraft's groundspeed."
Instructor: "Where do we get that information?"
Student: "We get it from the Navigation Computer System."
Instructor: "What do we do with the groundspeed?"

(The exchange then continues until the student has properly and correctly computed an ETA).

In the mixed approach to instructional interaction, learners are first told how to accomplish the process (as in the directive approach) and then questioned through it as they perform it (as in the questioning approach). Remember, each of these strategies involve various ways of interacting with the learner to present a previously established procedure. The learner's ability to perform the process correctly and autonomously indicates successful acquisition of the procedural skill prescribed by the learning objective.

All three interaction strategies mentioned previously represent the mean and the extremes for common instructional interaction strategies within the context of procedural skill acquisition. So, which of these strategies is most effective for reducing fragile knowledge construction? Are some strategies more effective than others in eliminating or reducing the construction of particular types of fragile knowledge?

Brophy (1979) and Good (1979) conclude that direct instruction has important advantages and is clearly superior to other approaches for producing mastery of basic skills. Advocates of questioning approaches point to the ability to encourage learners to reflect and thus stimulate thinking and learning of the process or procedural skill being learned (Aschner, 1961). Yet, Adler (1980) and Perkins (1992) argue that the best interaction strategy is to provide a didactic and questioning approach together as a congruent instructional interaction strategy. Who is right? Does the interaction strategy even matter at all? The purpose of this study is to find an answer to these questions.

Hypotheses

This experiment examined the effect of common instructional interaction strategies on the construction of fragile knowledge in learners. Furthermore, the experiment assessed whether providing learners with executive control strategies can inhibit the production of fragile knowledge during initial procedural skill

acquisition. Prominent educational theorists and researchers hold conflicting positions on the efficacy of various instructional interaction strategies to produce rich understanding (and less fragile knowledge) in the learner. This study examined each of these positions and tested their effectiveness in eliminating or reducing the construction of fragile knowledge.

Hypothesis 1 The Effect of Interaction Strategies on Fragile Knowledge

Construction

Learners who receive minimal or directive type strategies will construct more fragile knowledge than learners who received more facilitative (questioning or mixed) styles. With respect to the first independent variable, instructional interaction strategies, which had four levels: no instructional interaction, directive, questioning, and mixed (directive and questioning), the results of the experiment will show that the interaction strategy makes a significant difference on the learner's construction of fragile knowledge. This will be indicated by the no instructional interaction and directive groups presenting lower total scores on the posttest. The questioning and mixed groups will present higher scores on the posttest.

Hypothesis 2 The Efficacy of Executive Control Strategies

Regarding the second independent variable, executive controls, which had two levels: the explicit teaching of executive control strategies and no explicit teaching of executive control strategies, the results of the experiment will show that

possessing and using executive control strategies will minimize the construction of fragile knowledge. This will be indicated by higher scores on the posttest than the corresponding group that did not receive explicit instruction on executive control strategies. For example, the directive with executive controls group will achieve higher scores on the posttest than the directive without executive controls group and the same will follow for each of the remaining treatment groups.

Hypothesis 3 The Interaction of Instructional Interaction Strategy and Control Processes

Concerning the issue of possible interaction between the two independent variables, the results of this experiment will also show that there is no significant interaction between instructional interaction strategies and the explicit teaching of executive control processes. Thus, there will be no particular combinations of instructional interaction strategies and the absence or presence of executive controls that will produce statistically different results on the construction of fragile knowledge.

The theory contained in the literature of this chapter indicates that the interaction strategy should in fact matter. The theoretical argument is that encoding of condition-action productions takes place during the associative stage of procedural skill acquisition. In keeping with the information-processing model, different knowledge compilers should produce different encoding of condition-

action productions. Input from domain experts to the compiler or, ultimately, the compilation process should produce encoded condition-action productions that are more stable and less tenuous than unassisted knowledge compilation. Thus, assisted compilation should be less fragile or contain less fragile knowledge. Furthermore, encoding executive control processes along with the new procedural skill should provide learners with more tools to resolve impasses or repair bugs. This ability to autonomously resolve these impasses or bugs allows learners access to knowledge not previously attainable and stabilizes what was previously fragile knowledge. The research design, methodology, and material reflect the assertions posed in this chapter and help to ensure meaningful and useful results.

CHAPTER 3

EXPERIMENTAL DESIGN, METHODOLOGY, AND MATERIALS

Methodology

This study examined the relative effects of four common instructional interaction strategies: no instructional interaction, directive, inquiry or questioning, and mixed (directive and questioning) strategies along with the presence or absence of explicit instruction on executive control processes and their effects on the construction of fragile knowledge during initial procedural skill acquisition. Subjects were instructed in five basic navigation procedural skills according to the interaction strategy prescribed by their respective treatment group. The five basic navigation procedural skills are listed here in Table 3.1:

Table 3.1

Basic Navigation Procedural Skills

Determining an initial heading to fly to navigate to a prescribed geographic point
Determining the aircraft's actual position using a radio aid to navigation
Determining the aircraft's actual position using the RADAR
Computing a heading to alter the aircraft to when off the desired course
Computing an Estimated Time of Arrival (ETA)
Determining the aircraft's most probable position in the future

This chapter provides a detailed description of the participants, design, experimental materials, instrumentation, experimental procedures, and evidence of compliance with the assumptions for the statistical analyses conducted in this study.

Participants

One hundred and eighty-four freshmen undergraduate students enrolled in an introductory aviation science course participated in this study. AV100 (Introduction to Aviation) is a required course for all first-year cadets at the United States Air Force Academy. This study was conducted during the Fall 1995 semester. There were approximately 159 males and 25 females, ranging in age from 17 to 20. The students entering the Academy are selected from the applicants who typically score in the top twenty-five percent on the SAT/ACT exams. The average SAT score was 1430. All students, regardless of academic major, are required to complete the core curriculum at the Academy. The core curriculum focuses on hard science and general engineering. No subject selected for this study had any formal navigation training. All subjects completed the Academy's summer training and orientation programs. The Academy environment for first-year cadets is very regimented, strict, and demanding. Twenty-one credit hours with several concurrent extracurricular activities is a typical load at the Academy. Consequently, first-year cadets are used to a highly proceduralized learning and living environment and are compliance oriented toward authority. Summer training and orientation programs acclimated the cadets to the

military instructional environment before the study began. They also completed the introductory microcomputer orientation for first-year cadets. The orientation provided the subjects with specific microcomputer training on hardware, start-up procedures, keyboarding and use of the mouse, operating systems, operation of the local area network, and word processing. At the time this study was conducted, subjects had already completed assignments on their computers for other classes such as English, history, physics or chemistry which was evidence of their proficiency with the same microcomputer system that the simulator is based on. The students' reading skills were tested during inprocessing to the Academy and were at least an 11.5 reading level on the SRA reading scale for both speed and comprehension.

Student participation in this study was part of their normal core academic schedule, specifically for this Aviation Science class. A pretest assessed their level of prior knowledge of basic navigation. The pretest was a parallel form of the posttest. The test covered the same basic air navigation principles and procedures as the posttest. The purpose of the pretest was to assess the amount of prior knowledge the subject possessed prior to the treatment. Any subject who scored above 80% was considered to have a significant amount of prior knowledge and was not selected for participation in the study. The eighty percent cut score on the pretest was established at the recommendation of Academy institutional research personnel who have conducted numerous studies on Academy cadets. Academy cadets are very high

ability subjects who are highly motivated in this particular subject area. However, no subjects were actually eliminated from the study due to a significant amount of prior knowledge because the highest score on the pretest was 76%. The participants were randomly assigned to a class section and each class section was randomly assigned to one of eight different treatment groups. Ten sections out of a possible sixty sections were selected to participate in this study. Each section contained approximately 20 subjects who were randomly assigned by computer to that particular section. The subjects were motivated by the typical pressures of a competitive academic environment and special, additional, highly-desired incentive activities for those that distinguished themselves by their performance on the pre and posttest instruments. The tests used in the study were part of their regular academic program in AV-100 and counted toward their class standing. Class standing determined who received the additional incentive activities.

Design

The design of the experiment was a 4 X 2 factorial design (see Table 3.2 below) in which the effects of the absence or presence of executive control strategies within four different instructional interaction strategies were tested for their effects on the amount of fragile knowledge constructed during initial procedural skill acquisition.

Table 3.2

Experimental Design

Instructional Interaction Strategy

	No Interaction	Directive	Questioning	Mixed
Executive Controls	Group 1	Group 3	Group 5	Group 7
No Executive Controls	Group 2	Group 4	Group 6	Group 8

The experimental design followed Campbell and Stanley's (1963) pretest-posttest, control group design. The graphical depiction of the experiment is:

R O X₁ O
R O X₂ O
R O X₃ O
R O X₄ O
R O X₅ O
R O X₆ O
R O X₇ O
R O O

The first independent variable was the instructional interaction strategy. These strategies included: no instructional interaction, directive, questioning, and Mixed (directive and questioning) interaction strategies. The second independent variable was absence or presence of explicit instruction on executive control processes to double-check work or provide a broader and deeper understanding of the concepts and principles underlying the procedures.

Eight treatments were used in this experiment. Each of these treatments was composed of combinations of the two independent variables and was depicted earlier in Table 3.2 entitled "Experimental Design."

Variables Studied

The relative effects of two independent variables were studied. The first independent variable was the interaction strategy used, with four levels. The second independent variable was the presence versus absence of explicit instruction on executive control processes. This independent variable had two levels.

Independent Variables

Instructional Interaction Strategy. The effect of varying the instructional interaction strategy (one independent variable with four levels) was the first independent variable studied (see Table 3.2). This experiment tested common interaction strategies. These common instructional interaction strategies were no instructional interaction (the control group), directive strategies, questioning strategies, and mixed (directive and questioning) strategies.

Executive Control Processes. The second independent variable studied was the effect of explicit instruction on executive control processes (one independent variable with two levels). Perkins (1985) pointed to direct instruction on executive processes as a significant inhibitor of fragile knowledge construction. Eight treatment groups, as described previously, tested this posit.

Dependent Variables

The dependent variables were the amount and types of fragile knowledge that were constructed as a result the instructional interaction strategy the subject received. The dependent measure was a multiple-choice immediate posttest given at the conclusion of the treatment to assess the amount of fragile knowledge the subject possessed. The test represented a solid grasp of navigational concepts, principles, and procedures. A low score on the measure indicated the presence and degree of fragile knowledge present in the subject. A detailed description of the posttest is provided under the discussion of the individual instruments.

Treatments

There were eight treatment groups (see Table 3.2 earlier in this chapter). Groups 1 and 2, groups 3 and 4, groups 5 and 6, and groups 7 and 8 differed by the instructional interaction style or strategy they received. Each odd numbered group additionally differed by the presence or absence of explicit instruction on executive control processes that could be used to cross-check or provide a better understanding of the air navigation process.

Treatment groups 1 and 2 did not receive any instructional interaction. Group 1 was provided information on executive control processes by additional text covering these subjects. Group 2 was the control group. This treatment group was

not provided any instructional interaction or the additional coverage on executive control processes in its text.

Treatment groups 3 and 4 were given directive or didactic instruction on navigation principles and procedures. Subjects in this group were told what to do and how to do it from the beginning until the end of the simulator mission. Group 3 was given additional instruction on how to cross-check their work, identify and correct their own errors, and orient themselves strategically. Group 4 was not provided with that instruction.

Groups 5 and 6 experienced a more facilitative instructional strategy. Instructors in this group used questions instead of making statements to lead subjects through the procedures. Instructors provided subjects in the 5th group with the key questions they needed to ask themselves to prevent or correct errors and orient themselves. Group 6 did not receive this instruction.

Groups 7 and 8 received a combination of interaction strategies from the two previous groups. Instructors used statements and questions to instruct subjects in this group. Once again, subjects in Group 7 were given explicit instruction on strategies and executive control processes to facilitate autonomous performance.

Materials

The primary device used for the experiment was a microcomputer-based simulation of the navigator station of an Air Force T-43A. The T-43 is a military

version of the Boeing 737-200 commercial airliner. The NAVSIM (navigation simulator) graphically reproduces the panel in the aircraft and is supported by the actual flight model for the Boeing 737 resulting in simulation that is realistic enough to reduce the number of inflight training missions.

NAVSIM runs on an IBM PC based microcomputer and requires at least an 80386 microprocessor, 1 MB RAM, 1 floppy disk drive, and an EGA monitor. The actual system used for the experiment was an 80486DX/66 MHZ PC with 8MB RAM, 120B hard drive, and an SVGA monitor. The NAVSIM has been used to train students and instructors in the T-43 for the past five years. The software is updated regularly to accurately reflect changes to the aircraft's systems and performance.

The other materials used were standard Air Force issue items. These items included a current aeronautical navigation chart for the route to be flown, a navigation plotter, a Dead Reckoning Computer, a current IFR Supplement, and a navigation worksheet.

Topic Selection

Three fundamental concerns prompted the selection of the subject. The first factor in the topic selection was the concern to address a fundamental, authentic, problem. Fragile knowledge can have dire consequences. Educational professionals have an ethical responsibility to address the issue of fragile knowledge and any influence they might have on the construction of it in the products they produce or the

people they instruct. The second factor was the need to teach a new procedural subject to motivate the learners. Teaching a new subject reduced possible contamination from prior general knowledge or experience. The need for a large number of subjects was the final factor in the selection of this particular topic for the study. A sufficiently large sample was required to cover the range of common interaction strategies, examine the effect of strategic controls within these groups, and retain statistical power. Navigation is a good candidate because all first-year students at the Air Force Academy are required to complete the course to graduate.

Once the academic subject area was established, ten subject matter experts reviewed the course content and objectives to establish the content validity of the instructional materials. The Subject Matter Experts identified five primary procedural skills used in basic air navigation (see Table 3.1). These procedures and their underlying concepts and principles were taught lecture style in the first four lessons of the course (eight contact hours). This experimental treatment used the actual training methods and materials the Air Force Academy uses to teach flight training students to navigate the T-43. Only the instructional interaction strategy was changed for this study; the goals, objectives, content, methods, or materials were not altered for the experiment.

Instruments

Pretest and Posttest

These two tests were instructor developed multiple choice examinations designed to measure the subjects' ability to perform the five basic navigational procedures (see Table 3.1) and test their understanding of the concepts and principles underlying the procedures.

Each test contained 21 multiple choice questions with an additional 29 fill-in-the-blank substeps (see Appendices D and E). Each question required the subject to demonstrate his or her ability to perform an entire process or a part of one of the five basic navigation procedures mentioned earlier. To answer these questions subjects had to refer to print screens from the simulator which were included as supplemental material in the test. This provided graphical depictions of real-world conditions which the subject then had to interpret just as they would inflight. Each question had three or four possible answers, one correct answer and two or three distracters. The distracters were based on fragile knowledge of navigational concepts, principles, or procedures. The lower the subjects' score on the instrument the higher degree of fragile knowledge the subject possessed.

The pretest and posttest were initially developed by a highly experienced instructor. Ten subject matter experts then reviewed the instruments for their content validity, comprehensiveness, and accuracy. The ten subject matter experts also

reviewed the distracters in each question to ensure that these distracters represented valid examples of the common types of fragile knowledge as defined in the definitions section of chapter 1. The tests were changed based on input from the subject matter experts until a consensus was reached among the ten subject matter experts. Parallel forms were used to reduce testing effects and to ensure the security and integrity of the instruments. Recent graduates of the course were used to conduct a formative evaluation on both instruments. The formative evaluation group took both the pretest and the posttest during the same testing session. Results of the formative evaluation were used to improve the form and the function of the pre and posttest instruments. An item analysis showed the parallel forms reliability to be .88.

Procedure

Pilot Study

Once the instrumentation was finished, I conducted a pilot study. I randomly selected eight additional recent graduates to participate in the pilot study. These participants were randomly assigned to one of four possible treatment groups in the pilot study. The materials and procedures mirrored the main study. Results from the pilot study were generally in the hypothesized directions. Only minor changes were made as a result of the pilot study. These changes generally focused on clarifying verbiage in the instructions given to the subjects during the simulator mission.

The experimental procedure followed a pretest, intervention, and posttest sequence. The pretest was administered immediately after the regular academic portion of the course. The treatment was conducted as two instructional practice simulator missions. The immediate posttest was a mid-course examination.

Pre-Treatment Training of Instructors

Variability among the sixty instructors who participated in this study was a significant concern. Several steps were taken to minimize this possible effect. First, instructors were sent an overview of the study with sufficient details explaining the purpose, scope, methodology, and procedures of the research effort. I then held a meeting with the instructors to provide direct interaction and answer any questions before instructor training commenced.

Instructor training consisted of a one hour and forty minute practice teaching simulator mission. I gave each instructor a job aid to remind them of how to conduct their interaction with the subject according to their treatment group and a checksheet to remind the instructor of the content that needed to be covered during the lesson. During the practice mission on-the-spot corrections and constructive feedback were given when instructors deviated from the prescribed interaction strategy.

During the actual treatment, instructors used the same job aids from the practice mission to remind them of their interaction strategy roles. I continued to provide on-the-spot corrections to the offending instructors when they deviated from

their prescribed roles. If I had to provide more than one correction to an instructor I rejected his or her data.

Classroom Pretest

I administered the pretest in the classroom prior to the start of the fifth classroom lesson on navigation principles. By this point, subjects had attended eight contact hours of classroom. The pretest was a parallel form of the posttest. The pretest took twenty-two minutes for the quickest student and thirty-one minutes for the slowest student. The classroom instructor told the subjects that the test would count toward their class standing and opportunity for incentive flights. No one gave the subjects any feedback on how they performed on the pretest. Furthermore, they were restricted from discussing anything about the test with anyone else or going back and reviewing any of the content areas on the test until after completing the second simulator mission (which included the posttest).

Assignment to Treatment

The participants were randomly selected and randomly assigned to one of eight treatment groups. Here's how this was accomplished. First, the Registrar segmented the course offering into six modules. Each module contained ten sections (one section contained approximately 20 students). Three modules were offered per semester, and each module occurred one after the other. Then, the scheduling computer randomly assigned each subject to one of the sixty possible sections of AV-

100 within these modules. The computer did this by alphabetically assigning each participant to the first available section until the section was full. I conducted this study during the fall semester; so, that left three modules to choose from. Due to coordination problems with the department, I wasn't able to conduct the study until late in the semester. The coordination problem limited my access, and effectively made the choice of which module to study for me. I got together with the Course Director and we each picked random numbers from one to ten to assign each of the ten sections within the module to one of the eight treatment groups.

Instructional Intervention

I gave the subjects the pretest when they arrived for their first simulator mission. The instructors started the simulator mission once all the subjects had finished the pretest. Each group had approximately twenty students. Additional instructors were used to reduce the student to instructor ratio to 4:1. All simulator missions started at the same prescribed geographical point, flew a prescribed route, and ended at an established termination point. Only the instructional interaction style and instruction on executive control processes varied by treatment group.

Subjects started the second simulator mission immediately after they arrived. The second simulator mission was identical to the previous one. Instructors administered the posttest when the subjects either completed the mission or could no

longer continue the mission. The instructors thanked and released the participants once they completed the posttest.

Data Collection

I handscored the multiple-choice pre and posttests to prevent errors due to machine misfeeds or the mismarking of answer sheets. I entered student responses to each question along with pretest and posttest scores directly into the SPSS Data Editor. This served as the master database for all statistical analyses. This database also contained the pre-study data collected earlier. All simulator missions were recorded on 3.5" floppy diskettes. Every action the subject did during the entire mission was recorded for future reference and could be played back for analysis.

Data Analysis

SPSS for Windows 6.1, Statistical Package for the Social Sciences (SPSS)(1994), a microcomputer based statistics package was used on an IBM based 80486 microcomputer, to conduct all statistical analyses. All data were entered directly into the program's data editor.

I performed an Analysis of Covariance (ANCOVA) on the total score obtained on the posttest, with the total score obtained on the pretest as the covariate. The categories of the 4 X 2 factorial design were instructional interaction style by executive control process. Also, I conducted a Multivariate Analysis of Variance (MANCOVA) to determine whether specific instructional interaction strategies

produced particular types of fragile knowledge. I did this by recoding each student response to every question on the posttest into one of the five types of fragile knowledge that the response represented. For example, if a subject selected answer B to question number one and the subject matter experts had previously determined that answer B was a valid example of inert knowledge, then the subject's response was recoded into one instance of a display of inert knowledge. For the MANCOVA, the instructional interaction strategy was the factor variable and the five types of fragile knowledge (inert, partial, etc.) were the dependent variables. As a result of the recoding, these dependent variables contained the number of instances each subject displayed that particular type of fragile knowledge on the posttest. An alpha level of .05 was used for all statistical analyses. A discussion and evidence of compliance with the assumptions necessary for conducting a valid analysis of variance and multivariate analysis of variance follows.

Assumptions

The assumptions for analysis of covariance are : (1) random and independent sampling, (2) samples from a normal distribution, (3) true variances of each group are equal, (4) independence of means and variances, (5) at least interval scaling (Gabriel & Hopkins, 1974, p. 378), (6) a correlation between the covariate and the dependent variable, and (7) homogeneity of regression (Keppel & Zedeck, 1989). The students were randomly assigned to groups according to the plan presented earlier in this

chapter. No subjects were assigned to more than one treatment group. The number of participants in each treatment group varied from 11 to 31 in the final statistical analysis. Stem and Leaf Plot analysis of posttest scores revealed that students fulfilled the requirements for a normal distribution. Additionally, posttest scores further indicated that each group followed a normal curve centered around a 58.8% mean with an 11.8% standard deviation. Cochran's C and Bartlett-Box homogeneity of variance tests conducted on the posttest data. Cochran's C(17,8)=.14569 p=1.000 and Bartlett-Box(7,14,688)=.06243 p=1.000 supported the null hypothesis that all cell variances were equal. Data in Tables 3.2 and 4.1 support the independence of means and variances. Interval scaling was assumed by constructing the posttest so that scores ranged from 0 to 100. Correlation between the covariate and the dependent variable is established by the fact that the pretest (covariate) was a parallel form of the posttest. Independence was achieved by taking the pretest measure before the treatment occurred. Homogeneity of regression was verified by examining the residual plots for each treatment group. All plots showed only minor deviations from linearity. The deviations between the pretest residuals and posttest residuals were in the same direction and nearly the same amounts.

The assumptions for multivariate analysis of variance are an extension of the assumptions for univariate analysis of variance. As mentioned previously, the assumptions for analysis of covariance are : (1) random and independent sampling, (2)

samples from a normal distribution, (3) true variances of each group are equal, (4) independence of means and variances, (5) at least interval scaling (Gabriel & Hopkins, 1974), (6) a correlation between the covariate and the dependent variable, and (7) homogeneity of regression (Keppel & Zedeck, 1989). These assumptions still hold for multivariate analysis with the added assumption that the composite observations are normally distributed, equally variable in the populations sampled, and independent (Gabriel & Hopkins, 1974). The data used in this analysis were the same data used in the previous univariate analysis. Posttest responses were recoded to represent the type of fragile knowledge indicated by the answer the subject selected during the posttest measurement. Since these assumptions have already been met, they will not be addressed again. However, compliance with the additional assumption posed by the multivariate analysis has not yet been demonstrated, and a brief examination follows.

The assumption of normal distribution, equal variance, and independence of composite observations for the multivariate analysis was not met for the recoded data. Analysis of stem and leaf plots for the five types of fragile knowledge (conglomerative, inert, misplaced, naïve, and partial) showed a normal distribution for all types except inert knowledge. The inert category also violated the homogeneity of variance assumption with a Cochran's $C(36,4)=.62344$ and $p<.0001$. Multivariate

tests for homogeneity of dispersion were also violated. These tests revealed a Box's M of $F=157.3$, $df(45,30425)$, $p<.0001$.

Although multivariate assumptions for all five categories were not met due to the effect of the inert category, assumptions for the remaining four categories were met. Since the assumptions for the remaining categories were met, a MANCOVA was conducted with the inert category removed from the analysis. The PRETEST was used as a covariate to account for aptitude effects and keep this analysis consistent with the ANCOVA for the main effects of the first research question.

With the assumptions for the analyses met, the analyses were completed, and the results of the study follow.

CHAPTER 4

RESULTS

This chapter presents the results of the statistical analysis of the collected data. The primary focus of the study was the impact of common instructional interaction strategies on the construction of fragile knowledge during initial procedural skill acquisition. It also examined whether certain interaction strategies produced particular types of fragile knowledge. The secondary focus of the study was whether explicit instruction on executive control strategies can influence fragile knowledge construction.

Table 4.1

Summary of Means and Standard Deviations by Instructional Interaction Strategy and Executive Controls

Instructional Interaction Strategy		Executive <u>Yes</u>	Controls <u>No</u>	Totals for <u>Strategy</u>
None (Control Group)	Pretest			
	M	46.3	34.2	39.1
	SD	9.6	13.0	13.1
	Posttest			
	M	59.7	55.1	60.0
	SD	11.4	11.4	11.6
Directive	n	11	16	27
	Pretest			
	M	38.6	46.2	42.4
	SD	10.9	10.2	11.0
	Posttest			
	M	55.8	55.0	55.4
Questioning	SD	10.6	10.7	10.5
	n	13	13	26
	Pretest			
	M	44.8	45.1	44.9
	SD	10.3	11.4	10.6
	Posttest			
Mixed	M	57.4	55.7	56.8
	SD	11.4	11.8	11.5
	n	31	17	48
	Pretest			
	M	46.0	43.7	45.1
	SD	11.5	16.1	13.3
Executive Controls Totals	Posttest			
	M	63.3	65.2	64.0
	SD	11.5	12.3	11.7
	n	29	17	46
	Pretest	Yes	No	
	M	44.4	42.2	
	SD	10.8	13.6	
	Posttest			
	M	59.5	58.0	
	SD	11.5	12.2	
	n	84	63	

Effect of Instructional Interaction Strategy: Research Question #1

Does the instructional interaction strategy used influence the construction of fragile knowledge during initial procedural skill acquisition in the learner? Yes, a main effect for instructional interaction strategy was found in the ANCOVA ($F(3,138)=5.43$, $p=.001$) see Table 4.2 and Figure 4.1 below. Post-hoc Scheffe comparison indicated that the mixed strategy group (the group that received the combined directive and questioning interaction strategy) scored significantly higher on the posttest than the other groups.

Table 4.2

Analysis of Covariance Summary by Independent Variable

DEP VAR: POSTTEST		COVARIATE: PRETEST		N: 147	
SOURCE	SUM SQUARES	DF	MEAN-SQUARE	F-RATIO	P
INST INTER STRAT .001*	1590.18	3	530.06		5.43
EXEC CONTROLS .784	7.33	1	7.33		.08
INST INTER STRAT by EXEC CONTROLS	274.11	3	91.37	.94	.425
ERROR	13466.57	39	97.58		

* $p < .05$

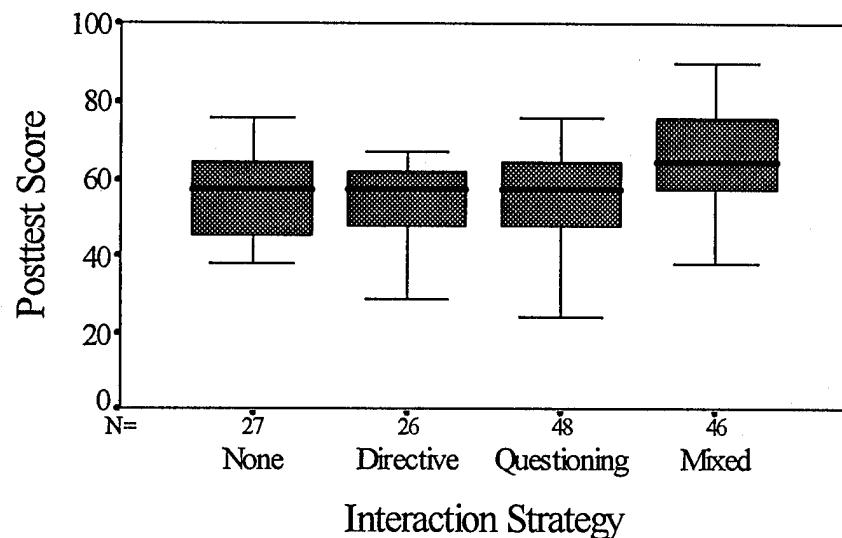
Note. The abbreviations used in this table are as follows:

INST INTER STRAT-Instructional Interaction Strategy. This is one of four common elemental methods or tactics for conveying instruction to the learner
EXEC CONTROLS-Executive Control Strategies. These are additional procedural tools used to control and cross-check the execution of the

procedure. Effect size and observed power at the .05 level were .264 and 1.00 respectively.

Figure 4.1

Posttest Scores by Instructional Interaction Strategy



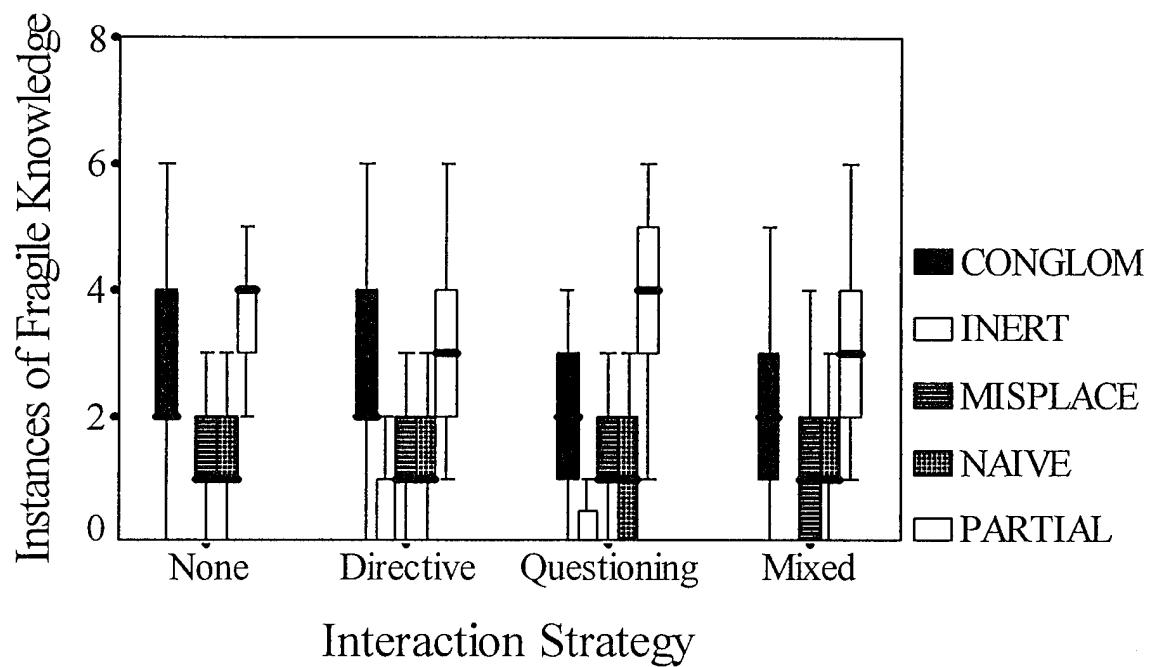
Types of Fragile Knowledge Construction: Research Question 1a

Do certain instructional interaction strategies result in a particular type of fragile knowledge construction over another type? No significant differences were found among the five types of fragile knowledge for any specific instructional interaction strategy (multivariate $F(12,423) = 1.69$, $p=.067$). See Figure 4.2 for a graphical summary of the results. The multivariate effect size and power at the .05 level were .046 and .86

respectively. No further analyses were conducted on types of fragile knowledge construction.

Figure 4.2

Instances of Specific Types of Fragile Knowledge by Interaction Strategy



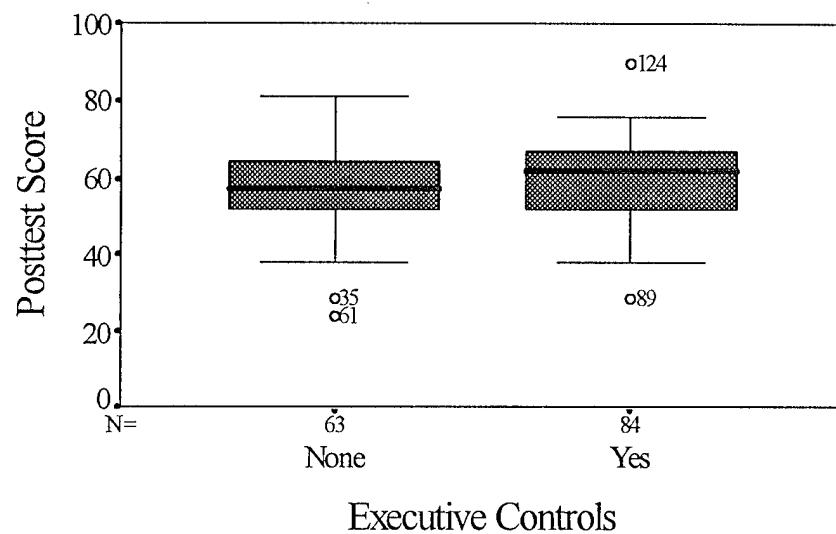
Effect of Executive Controls: Research Question #2

Does the explicit teaching of executive control processes (cross-checks and double-checks) influence the construction of fragile knowledge during initial procedural skill acquisition? No, there was no main effect for executive controls ($F(1,138)=.08$, $p=.784$). See Figure 4.3 for a graphical presentation of the results of this analysis. Furthermore, there was no

interaction of instructional interaction strategies and executive controls ($F(3,138)=.94$, $p=.425$).

Figure 4.3

Posttest Scores by Executive Controls



Now that we've seen the numerical results of the statistical analysis, what does all this mean in terms of the study. It's now necessary to look at the results and interpret them in light of the instructional theory that was presented in Chapters 1 and 2. What implications do these results have for educational professionals who are concerned about fragile knowledge construction in learners?

CHAPTER 5

SUMMARY, DISCUSSION, AND RECOMMENDATIONS

Summary of the Study

This study focused on the effects of four common instructional interaction strategies on the construction of fragile knowledge. It also examined whether the explicit teaching of executive control strategies had an effect on fragile knowledge construction. This chapter provides a summary of the research effort to answer these questions, a discussion of the results with implications for the improvement of instruction involving procedural skill acquisition, and recommendations for future studies in this area.

The central research question was whether the strategy used to interact with the learner effects the stability of the knowledge the learner acquires? If so, does a particular interaction strategy tend to create a specific type of fragile knowledge? Furthermore, does the explicit teaching of executive control strategies also influence the construction of fragile knowledge in the learner?

The treatment consisted of common variations in the way instructors interacted with the students. Forty-three instructors were trained and participated in the administration of the treatment. The instructional interactions included no int

eraction with the student, directive interactions, questioning interactions, and a mix of directive and questioning interactions. Explicit instruction on executive control strategies was also provided to only one of the two sub-groups within each instructional interaction strategy treatment group. The executive control strategies were cross-checks and double-checks of the computations from each of the navigational procedures.

Subjects in the No Instructional Interaction without Executive Controls group were informed of the lesson objective, given the coursebook, lesson materials, and sent to the simulator. Subjects in the No Instructional Interaction with Executive Controls groups were given the same instructions and materials except that their coursebook provided instruction on executive controls.

Subjects in the Directive without Executive Controls group were explicitly told how to accomplish each step of the required procedures. Those in the Directive with Executive Controls group received the same style of instruction with the addition of explicit teaching of specific strategies to control the execution of the required procedures.

Participants in the Questioning without Executive Controls group were questioned all the way through each step of the required procedures. The questions focused on how to accomplish each step. In the Questioning with Executive Controls

group subjects were also questioned through strategies to control the execution of the required procedures.

The Mixed without Executive Controls group received a mixture of both the directive and the questioning approaches. The Mixed with Executive Controls group received the same approach with the addition of instruction on how to control process execution.

An ANCOVA was conducted to examine the data for main effects and any interaction between the independent variables. Pretest results were used as a covariate to account for aptitude effects. Results of the analysis showed that the mixed group performed significantly better than the other three groups on the posttest. The posttest was a measure of the amount of fragile knowledge a subject possessed. A MANCOVA for types of fragile knowledge constructed showed no significant differences between treatment groups. An ANCOVA for the effect of executive controls on fragile knowledge construction showed no significant differences between treatment groups.

Discussion

Are certain instructional interaction strategies more effective than others in minimizing fragile knowledge construction in procedural skill acquisition? If they are, do certain interaction strategies have a tendency to produce specific types of

fragile knowledge? Does explicit instruction on executive control strategies also help minimize fragile knowledge construction?

Epistemological differences have fueled the debate about which approaches to instructional interaction are the most effective. Each competing educational philosophy would answer these questions differently. A proponent of direct instruction would support telling learners what they need to know. A proponent of discovery learning would want to put them in an environment that is conducive to learning and let them learn. Proponents of the Socratic method might want to challenge learners to find answers by using questions to allow them to probe their understanding. Adler (1980) and Perkins (1992) suggest a mixed approach. They would provide didactic instruction, coach them by observing and guiding, and follow up with the Socratic method. With all these apparently competing approaches to achieving the same objective, who's right? Which method is most likely to reduce fragile knowledge construction during procedural skill acquisition?

The results of this study support the importance of using mixed instructional interaction strategies to minimize the construction of fragile knowledge in learners. Subjects in this study that were initially provided a directive approach to instructional delivery supported by a shift to a questioning style during learner performance performed significantly better than subjects who received no instructional interaction or only the directive or questioning approach.

Furthermore, the group that received no instructional interaction performed equally as well, if not better in some cases, than the directive group or the questioning group. Another way of looking at this is that the directive or questioning groups performed no better than the group that had no instructional interaction at all. Based on post treatment interviews one possible explanation for this is that the directive approach did not accommodate questions from the students. The students may have had questions, but the instructors addressed them. The questioning approach created ambiguity and insecurity because this interaction strategy created more questions in the learner than it answered. Subjects frequently stated that they understood the material but the questioning made them unsure of their understanding.

Although certain groups produced more instances of fragile knowledge than others, no treatment group produced a statistically significant amount of any one specific type of fragile knowledge than any other group. This was expected. Furthermore, subjects who also received explicit instruction on executive control strategies performed better than other subjects in most instances; however, the difference in performance was not statistically significant.

Limitations

The answer to the first question of whether there are certain interaction strategies that minimize fragile knowledge construction is soundly supported by the

results of this study. The answers to the other two questions are less firmly supported due to methodological and theoretical problems with the study. Consequently, these results should be interpreted with caution.

The reason for caution, in regard to the question of whether certain interaction strategies produce specific types of fragile knowledge, is that the analysis done to examine this question was accomplished post-hoc. The primary purpose of the instruments used in the research was to detect the presence of fragile knowledge not to discriminate between the different types. Although the pre and posttests were able to discriminate between the different types of fragile knowledge, they did not present all five types equal opportunity in every instance throughout the entire measurement. For example, some questions contained the correct answer and instances of only one type of fragile knowledge as distractors. The effect of this would be to provide more opportunity to find significant difference with this type of fragile knowledge simply because it received more exposure than the other types.

The reason for caution with regard to the second main research question (whether explicit instruction on executive control strategies has an effect on fragile knowledge construction) is the theoretical interaction between executive control strategies themselves and the resultant effect of questioning or mixed directive and questioning interaction strategies. If subjects simply replicated the questions posed by the instructor during the initial delivery, then they in effect unintentionally

constructed an executive control strategy. For example, if an instructor questioned a subject on where to get a certain piece of data to solve a navigation equation required in a procedure, and the subject remembered this interaction, then the subject could use this to repair a procedural impasse that would have ordinarily resulted in inert fragile knowledge. The end result of this would have been that even though subjects were not given explicit instruction on executive control strategies, they could have constructed different, but effective, executive control strategies by themselves. Consequently, data would have shown no significant differences between groups that did or did not receive explicit instruction on executive control strategies. The results of this study support this interpretation.

Finally, although this study is theoretically generalizable to similar learning environments that involve complex procedural skill acquisition, the reader must be the one to make the generalization. This study examined high ability, highly motivated subjects in a rigid learning environment; other environments or conditions may vary significantly.

Recommendations

Based upon the results of this study, the most effective way to minimize the construction of fragile knowledge in learners during initial procedural skill acquisition is to open the delivery with a directive or didactic approach; then, shift to a questioning strategy as the learner performs the procedure. Other strategies may

work, but according to this study, they will have a tendency to produce more fragile knowledge.

Initial delivery should clearly highlight the critical attributes of the procedure and use an input-process-output approach to teaching each step in the procedure. The instruction should explicitly cover where to get input data from, what to do with it, and where put the result. This then becomes the input for the next step of the process or sub-process. Once this has been accomplished, instructional interaction should shift to a questioning style while the learner is performing the procedure. The questions used during this phase should center on where one gets data for process input, what to do with it, what to do with the results, and the learner's evaluation of the performance of the process.

Instruction involving procedural skill acquisition should avoid interaction strategies with the learner that are entirely directive or declarative in nature or interaction that is entirely question-based. A mix of the two strategies in the sequence presented above will produce less fragile knowledge in the learner.

Future Studies

Future studies on fragile knowledge need to address the issues still unresolved in this study and further examine why mixed strategies are better than the others. Finding answers to these questions would clarify our understanding of fragile knowledge and help to minimize its consequences.

The predisposition of certain instructional interaction strategies to produce specific types of fragile knowledge and the effect of executive control strategies are issues that remain unresolved in this study. Instrumentation designed specifically to detect the types of fragile knowledge constructed would resolve the first issue. Also, studies should be conducted on subjects of lower ability in an environment that is less competitive. Competitive subjects were more willing and better able to produce conglomerative fragile knowledge (combining disparate elements of knowledge to be able to produce an answer) than inert fragile knowledge (simply not answering the question). Conducting these studies would also help establish a range for the magnitude of the effect of interaction strategies on fragile knowledge construction. With regard to further examination of the effect of executive control strategies, changing the nature of the questions used during the study would eliminate the confounding nature of the interaction between the questions used to minimize the construction of fragile knowledge and the executive control strategies themselves. For study purposes, instructors should not use questions that learners can construct control strategies from by mere recall. When attempting to measure the effect of executive control strategies, avoiding questions like “where do you get this information?” or “what do you do with this data?” should eliminate the confounding effects in the study. However, it may be necessary to answer this question in a completely separate study. This should provide a more definitive answer as to

whether the explicit instruction of executive control strategies influences the construction of fragile knowledge.

Conclusion

Fragile knowledge can have significant consequences. Educational professionals have an ethical responsibility to minimize or eliminate the construction of fragile knowledge in learners. This study has shown that the instructional interaction strategies we use with learners has an effect on the amount of fragile knowledge they construct. Therefore, it is incumbent upon us as professional educators to prescribe, and properly implement, interaction strategies that have been shown to be effective against fragile knowledge construction.

Using a mixed strategy of declarative delivery initially and question-based support during learner performance has been shown to be an effective strategy. Avoidance of entirely declarative or question-based approaches is also effective in reducing the construction of fragile knowledge. While questions still remain as to the nature of fragile knowledge and the effect of executive control strategies, the question of whether or not how instructors or instructional systems interact with the learner effects their construction of fragile knowledge has been answered. The type or style of interaction with a learner effects the stability of the knowledge they construct. The tragic consequences that may be a result of fragile knowledge can be avoided by the use of effective instructional interaction strategies. Can we afford to

continue to use strategies that are economical or efficient but less effective in minimizing fragile knowledge construction and its consequences?

APPENDIX A

DATA SUMMARY FOR ANCOVA

Subject #	TreatGP	InstStrat	ExecCtrls	Pretest	Posttest
1	1	None	None	10	62
2	1	None	None	33	43
3	1	None	None	33	57
4	1	None	None	29	43
5	1	None	None	29	62
6	1	None	None	48	71
7	1	None	None	33	48
8	1	None	None	38	43
9	1	None	None	43	43
10	1	None	None	33	52
11	1	None	None	14	38
12	1	None	None	62	67
13	1	None	None	52	62
14	1	None	None	24	62
15	1	None	None	29	52
16	1	None	None	38	76
17	2	None	Yes	43	48
18	2	None	Yes	57	76
19	2	None	Yes	57	62
20	2	None	Yes	52	62
21	2	None	Yes	33	43
22	2	None	Yes	43	57
23	2	None	Yes	38	67
24	2	None	Yes	48	57
25	2	None	Yes	38	43
26	2	None	Yes	62	71
27	2	None	Yes	38	71
28	3	Directive	None	29	43
29	3	Directive	None	62	62
30	3	Directive	None	52	62
31	3	Directive	None	48	57

32	3	Directive	None	52	62
33	3	Directive	None	57	67
34	3	Directive	None	48	57
35	3	Directive	None	29	29
36	3	Directive	None	52	62
37	3	Directive	None	38	52
38	3	Directive	None	52	62
39	3	Directive	None	43	57
40	3	Directive	None	38	43
41	4	Directive	Yes	43	67
42	4	Directive	Yes	29	38
43	4	Directive	Yes	48	48
44	4	Directive	Yes	43	43
45	4	Directive	Yes	33	38
46	4	Directive	Yes	48	62
47	4	Directive	Yes	24	62
48	4	Directive	Yes	38	57
49	4	Directive	Yes	38	57
50	4	Directive	Yes	14	57
51	4	Directive	Yes	48	62
52	4	Directive	Yes	48	67
53	4	Directive	Yes	48	67
54	5	Questioning	None	43	57
55	5	Questioning	None	43	48
56	5	Questioning	None	48	57
57	5	Questioning	None	52	71
58	5	Questioning	None	52	52
59	5	Questioning	None	38	43
60	5	Questioning	None	52	62
61	5	Questioning	None	14	24
62	5	Questioning	None	48	52
63	5	Questioning	None	57	62
64	5	Questioning	None	38	76
65	5	Questioning	None	57	67
66	5	Questioning	None	48	52
67	5	Questioning	None	43	48
68	5	Questioning	None	43	57
69	5	Questioning	None	62	62
70	5	Questioning	None	29	57
71	6	Questioning	Yes	62	67

72	6	Questioning	Yes	38	48
73	6	Questioning	Yes	38	52
74	6	Questioning	Yes	52	62
75	6	Questioning	Yes	52	71
76	6	Questioning	Yes	31	57
77	6	Questioning	Yes	57	71
78	6	Questioning	Yes	38	38
79	6	Questioning	Yes	52	62
80	6	Questioning	Yes	43	48
81	6	Questioning	Yes	57	76
82	6	Questioning	Yes	57	67
83	6	Questioning	Yes	33	48
84	6	Questioning	Yes	38	48
85	6	Questioning	Yes	52	67
86	6	Questioning	Yes	38	43
87	6	Questioning	Yes	62	76
88	6	Questioning	Yes	38	38
89	6	Questioning	Yes	29	29
90	6	Questioning	Yes	43	48
91	6	Questioning	Yes	57	57
92	6	Questioning	Yes	33	62
93	6	Questioning	Yes	38	52
94	6	Questioning	Yes	57	62
95	6	Questioning	Yes	43	67
96	6	Questioning	Yes	33	57
97	6	Questioning	Yes	33	57
98	6	Questioning	Yes	38	67
99	6	Questioning	Yes	57	62
100	6	Questioning	Yes	38	62
101	6	Questioning	Yes	52	57
102	7	Mixed	None	57	71
103	7	Mixed	None	38	43
104	7	Mixed	None	43	62
105	7	Mixed	None	52	76
106	7	Mixed	None	5	67
107	7	Mixed	None	43	57
108	7	Mixed	None	19	57
109	7	Mixed	None	38	81
110	7	Mixed	None	62	81
111	7	Mixed	None	43	76

112	7	Mixed	None	62	81
113	7	Mixed	None	67	76
114	7	Mixed	None	62	67
115	7	Mixed	None	33	62
116	7	Mixed	None	38	52
117	7	Mixed	None	43	52
118	7	Mixed	None	38	48
119	8	Mixed	Yes	57	76
120	8	Mixed	Yes	43	43
121	8	Mixed	Yes	38	57
122	8	Mixed	Yes	52	76
123	8	Mixed	Yes	38	71
124	8	Mixed	Yes	67	90
125	8	Mixed	Yes	62	67
126	8	Mixed	Yes	43	62
127	8	Mixed	Yes	38	67
128	8	Mixed	Yes	43	57
129	8	Mixed	Yes	48	48
130	8	Mixed	Yes	52	62
131	8	Mixed	Yes	33	67
132	8	Mixed	Yes	62	76
133	8	Mixed	Yes	38	57
134	8	Mixed	Yes	43	76
135	8	Mixed	Yes	43	71
136	8	Mixed	Yes	33	52
137	8	Mixed	Yes	38	62
138	8	Mixed	Yes	24	57
139	8	Mixed	Yes	38	38
140	8	Mixed	Yes	76	76
141	8	Mixed	Yes	52	52
142	8	Mixed	Yes	33	71
143	8	Mixed	Yes	48	52
144	8	Mixed	Yes	48	67
145	8	Mixed	Yes	48	57
146	8	Mixed	Yes	38	71
147	8	Mixed	Yes	57	57

APPENDIX B
DATA SUMMARY FOR MANCOVA

Subject #	Partial	Conglom	Misplaced	Naïve	Inert
1	2	2	1	2	1
2	5	2	4	1	0
3	4	2	1	2	0
4	5	2	0	1	0
5	4	5	2	1	0
6	3	2	1	0	0
7	3	2	3	3	0
8	4	4	2	2	0
9	4	6	1	0	1
10	4	2	1	2	1
11	3	5	3	2	0
12	2	4	1	0	0
13	1	5	1	1	0
14	6	1	0	1	0
15	4	2	2	1	1
16	1	3	0	1	0
17	3	4	2	1	1
18	2	3	0	0	0
19	3	2	1	2	0
20	5	0	2	1	0
21	6	5	1	1	1
22	4	1	3	1	0
23	3	2	1	1	0
24	4	2	1	2	0
25	4	4	3	1	0
26	5	0	0	1	0
27	3	2	1	1	0
28	2	5	2	2	1
29	6	1	0	1	0
30	3	2	1	1	1

31	4	3	1	1	0
32	4	2	1	1	0
33	3	4	0	0	1
34	2	4	2	1	0
35	2	4	1	3	5
36	3	2	2	1	0
37	1	4	2	1	2
38	4	1	1	2	0
39	4	3	1	1	0
40	2	6	3	1	0
41	1	2	1	3	0
42	6	3	1	3	0
43	2	3	1	3	0
44	3	4	2	2	1
45	4	2	2	2	4
46	2	1	3	2	0
47	5	2	0	1	0
48	3	2	2	2	0
49	2	1	2	2	2
50	5	3	0	1	0
51	4	1	1	2	0
52	4	0	3	0	0
53	3	2	1	0	1
54	4	3	1	1	0
55	6	0	3	2	0
56	2	2	2	2	1
57	3	1	1	0	1
58	3	2	1	0	4
59	2	6	2	1	1
60	3	2	1	2	0
61	5	0	0	0	11
62	6	1	2	1	0
63	4	2	1	1	0
64	1	1	1	2	0
65	3	1	2	1	0
66	2	6	1	1	0
67	4	3	2	2	0

68	4	0	3	2	0
69	2	4	1	1	0
70	5	1	2	1	0
71	3	2	2	0	0
72	6	1	1	2	1
73	4	1	3	2	0
74	4	2	0	2	0
75	3	0	1	2	0
76	4	2	1	2	0
77	3	1	1	1	0
78	6	1	3	3	0
79	5	0	1	2	0
80	3	3	2	3	0
81	2	1	1	1	0
82	1	2	2	2	0
83	6	1	2	1	1
84	4	3	1	3	0
85	2	3	1	0	1
86	5	3	2	0	2
87	4	0	0	1	0
88	2	3	2	1	5
89	9	2	1	3	0
90	5	4	2	2	0
91	3	4	2	0	0
92	3	3	2	0	0
93	3	2	2	2	1
94	3	3	1	1	0
95	4	2	1	0	0
96	5	2	2	0	0
97	3	2	2	0	2
98	2	4	1	0	0
99	5	2	0	1	0
100	6	0	1	1	0
101	4	2	3	0	0
102	2	2	2	0	0
103	5	2	4	2	0
104	3	3	0	2	0

105	2	0	2	0	1
106	3	1	1	2	0
107	3	1	3	2	0
108	5	0	2	2	0
109	2	0	1	2	0
110	3	1	0	0	0
111	2	0	1	2	0
112	2	0	0	2	0
113	2	1	1	1	0
114	1	3	1	1	1
115	2	2	2	1	1
116	3	4	1	0	2
117	3	4	2	1	0
118	5	3	0	3	0
119	2	2	0	1	0
120	3	5	2	1	1
121	2	4	2	1	0
122	3	1	0	1	0
123	4	1	1	0	0
124	2	0	0	0	0
125	4	1	1	1	0
126	1	5	1	1	0
127	1	4	1	1	0
128	3	2	2	2	0
129	5	3	1	2	0
130	3	1	2	2	0
131	5	0	1	1	0
132	3	0	2	0	0
133	4	2	2	1	0
134	3	1	0	1	0
135	3	3	0	0	0
136	2	5	1	2	0
137	5	1	1	1	0
138	4	2	2	1	0
139	6	4	0	3	0
140	3	0	0	2	0
141	5	2	1	2	0

142	1	3	1	1	0
143	5	4	0	1	0
144	2	3	1	1	0
145	2	3	2	2	0
146	1	4	0	0	1
147	3	3	2	1	0

APPENDIX C

Pre-Study Questionnaire

Note

This data will remain strictly confidential. Under no circumstances will this be divulged to anyone other than you without your knowledge and prior written consent.

Name:

Age:

Gender: M F

Nationality: U.S. Other _____

SAT Composite Score:

High School GPA:

Is English your native language? Yes No

Previous Pilot Flight Experience (ex: Private Pilot, 40 hours)

Previous Navigation Experience (ex: Navy Sea Cadets, 2 yrs; NJROTC, Orienteering, etc.):

Are you Pilot or Nav Qualified? Yes No Don't Know

If you couldn't fly for the Air Force would you leave the Academy? Yes No

Were your favorite courses in High School Math and Science type courses? Yes No

Do you intend to pursue a technical/engineering major at the Academy? Yes No

Did you attend a Preparatory School? Yes No

Are you Prior Service? Yes No

If yes, were you an Air Crewmember? Yes No
or an Instructor/Trainer of Air Crewmembers? Yes No

Procedural Knowledge Memory Test Score _____

APPENDIX D

Name: _____

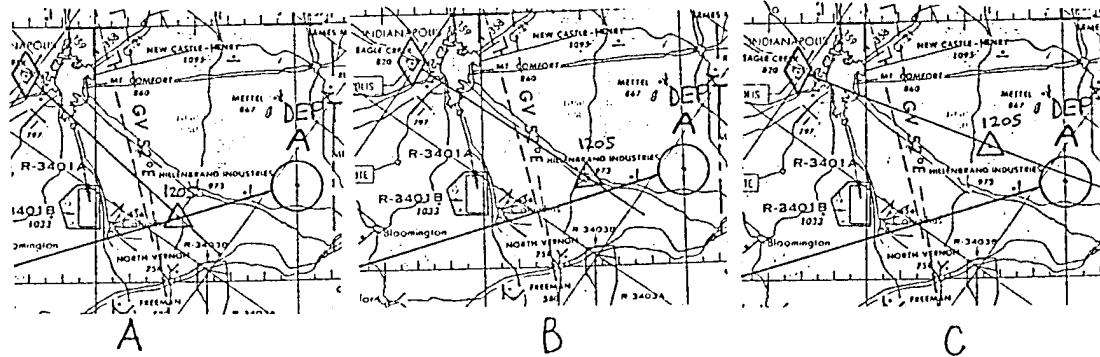
Aeronautical Knowledge Test #1

Choose the best answer. More than one answer per question may be correct.

1. Given the information shown in Figures 1 & 2., what heading should the pilot fly at the Departure Point?

- A. 254 degrees
- B. 256 degrees
- C. 266 degrees
- D. 268 degrees

2. Given the indications shown in Figure 2., which of the following most accurately depicts the aircraft's position? (Show your work on Figure 1.)



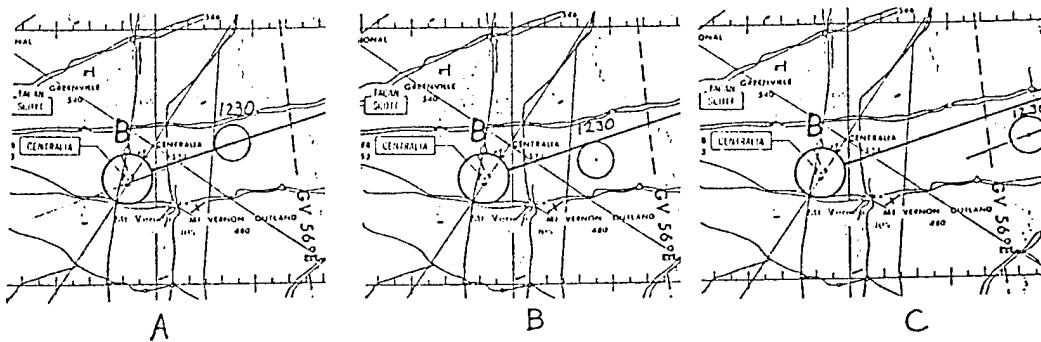
3. Based on the results of the fix resolved and plotted on Figure 1. and the indications in Figure 2., which magnetic heading should be flown to correct to course?

- A. 265 degrees
- B. 263 degrees
- C. 254 degrees
- D. 252 degrees

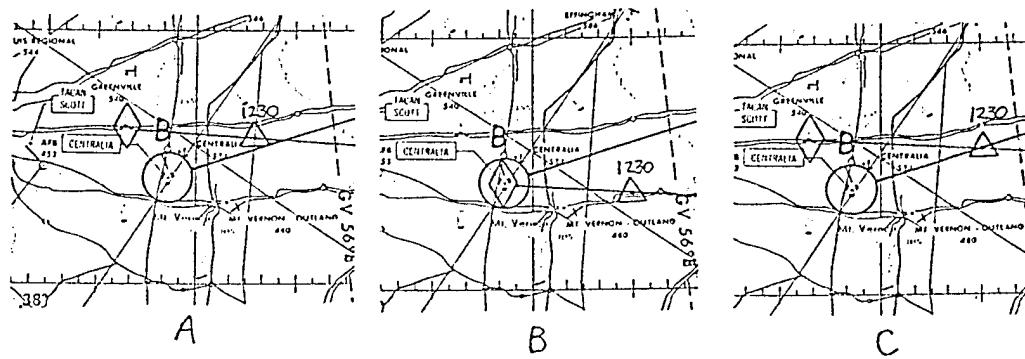
4. Using the information provided in Figure 3., which of the following is the most accurate ETA for Point B?

- A. 1216Z
- B. 1217Z
- C. 1234Z
- D. 1235Z

5. Using the indications shown in Figure 3., which of the following depictions most accurately represents where the aircraft will be at 1230Z?



6. Given the indications shown in Figure 4., which of the following most accurately depicts the aircraft's position at 1230Z?



7. The distance between each tick mark on a line of longitude on a JNC chart

- A. equals 2 NM
- B. equals 5 NM
- C. equals 60 NM
- D. cannot be determined because they are not equidistant due to convergence

8. Variation is the difference between

- A. True North and True Heading
- B. True North and Magnetic North
- C. True Course and Magnetic Course
- D. subsequent readings of the same instrument

9. The difference between Desired Course and Actual Course is called

- Variation
- Deviation
- Drift
- Slant Error

10. What effect will a 25 knot headwind instead of a 50 knot headwind have on your Proposed ETA to your final destination?

- It will take only half as much time to get there
- It will take twice as much time to get there
- Arrive later than originally planned
- Arrive earlier than originally planned

11. To maintain a planned/desired ground track on a JNC chart, a pilot must correct for

- crosstrack error and precession
- drift and precession
- variation and precession
- variation and drift

12. If a pilot must fly a heading of 260 degrees to maintain a track of 270 degrees and now is 10 minutes earlier to the arrival gate than originally planned which general direction is the wind coming from?

- Northwest
- Northeast
- Southwest
- Southeast

13. A Fix is a(n)

- estimate of the aircraft's current position
- measurement of the aircraft's current position
- estimate of the aircraft's future position
- measurement of the aircraft's future position

14. A Dead Reckoning (DR) position is a(n)

- estimate of the aircraft's current position
- measurement of the aircraft's current position
- estimate of the aircraft's future position
- measurement of the aircraft's future position

15. When taking a TACAN fix, where do we get the variation from?

- the Navigation Computer System (NCS)
- the line of variation halfway between the 2 points on the chart
- the line of variation closest to the TACAN station on the chart
- the IFR Supplement

16. What is the distance between N 21-18 W 105-15 and N 22-18 W 105-15?

- A. 60 NM
- B. 6 NM
- C. 1 NM
- D. .6 NM

17. How far will the aircraft have traveled if it's been maintaining 400 GS for 9 minutes

- A. 59.9 NM
- B. approximately 63 NM
- C. a distance equal to about one degree of latitude
- D. about 66 NM

18. If your Desired Course is 180 degrees and you experience 1 degree more right drift than you computed in your DR, where would you expect your fix to fall in relation to your DR assuming 240 NM between your last fix and current DR?

- A. 1 NM due east of the DR
- B. 4 NM due east of the DR
- C. 1 NM due west of the DR
- D. 4 NM due west of the DR

19. The angular difference measured in degrees between two points on a JNC chart is called

- A. True Course
- B. True Heading
- C. Magnetic Course
- D. Magnetic Heading

20. For fixing purposes, the RADAR is oriented to

- A. True Course
- B. True Heading
- C. True North
- D. Magnetic Heading

21. Which of the following navigational facilities does not provide enough information to establish a fix?

- A. VOR
- B. VORTAC
- C. VOR/DME
- D. TAC

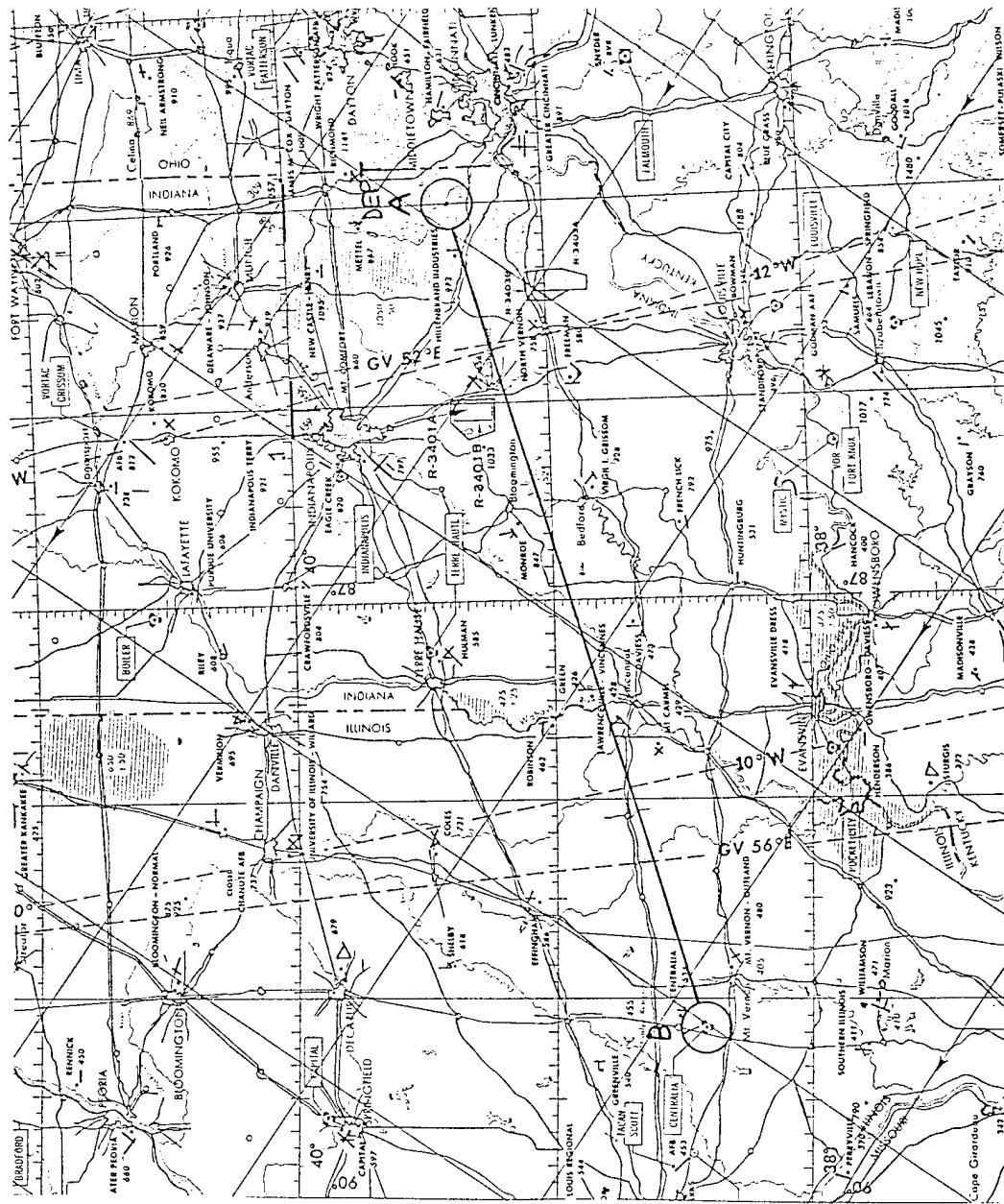


Figure 1. Chart Extract

Figure 2. TACAN Fix (CH 110)

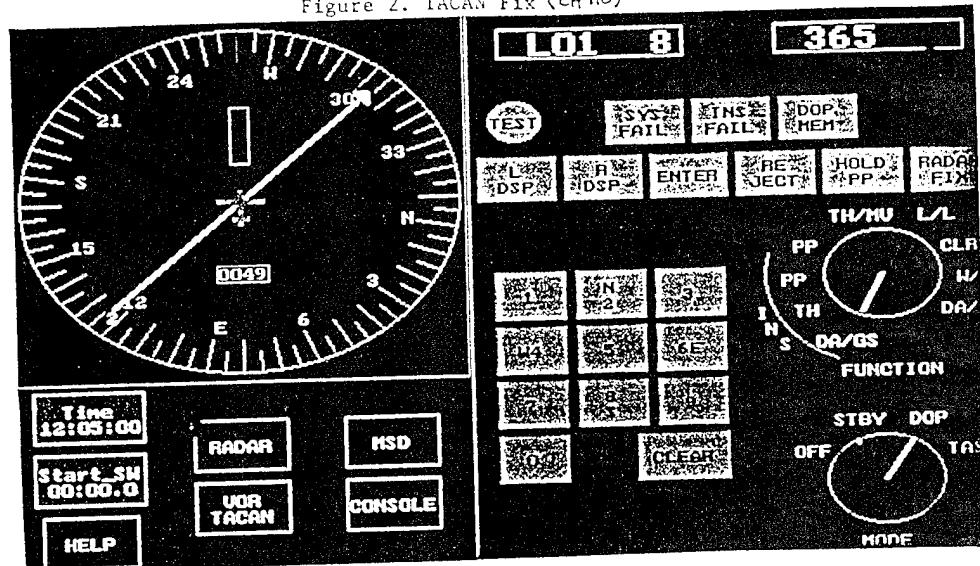


Figure 3. ETA and DR Information

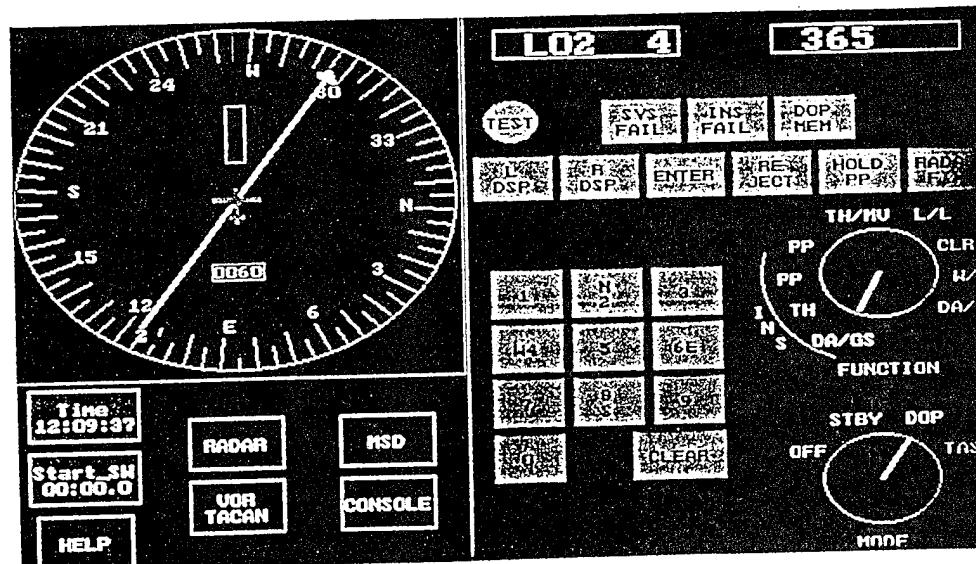
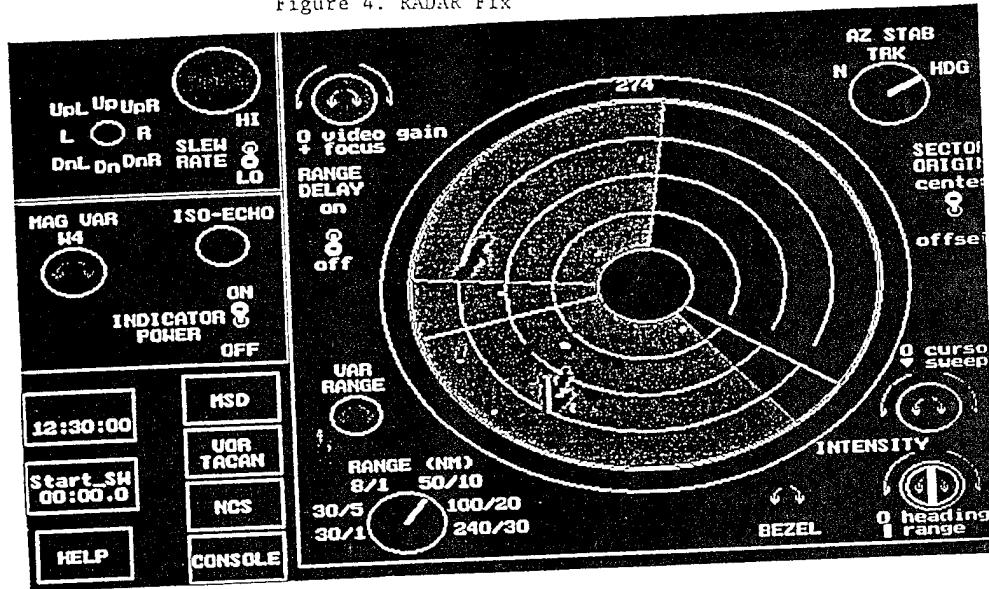


Figure 4. RADAR Fix



TC	MV	MC	DRIFT +L -R	HEADING TO FLY

FIX TIME 	TACAN CHANNEL / ID	RADIAL / DME	VARIATION +E -W	PLOT RADIAL / DME

TC TO NEXT POINT	VARIATION -E +W	MAGNETIC COURSE	DRIFT +L -R	MAGNETIC HEADING TO FLY

GROUND SPEED	HOW FAR TO NEXT POINT	HOW LONG TO NEXT POINT	TIME OF LAST FIX	ESTIMATED TIME OF ARRIVAL AT NEXT POINT

DR/FIX TIME 	MAGNETIC HEADING	DRIFT -L +R	MAGNETIC COURSE	VARIATION +E -W	TC TO PLOT
TIME SINCE LAST FIX		GROUND SPEED	DISTANCE TO PLOT		

TAKING A RADAR FIX:

RECORD TIME OF FIX
/ BEARING AND RANGE TO PLOT ON CHART

DOD
FLIGHT INFORMATION PUBLICATION
(ENROUTE)



IFR - SUPPLEMENT
UNITED STATES

This Supplement is issued EVERY EIGHT WEEKS

EFFECTIVE 0901Z 18 AUG 1994
TO 13 OCT 1994

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DMA STOCK NO. ENRXUSIFRSP



EFF. DATE 94230

Supplemental Materials

APPENDIX E

Name: _____

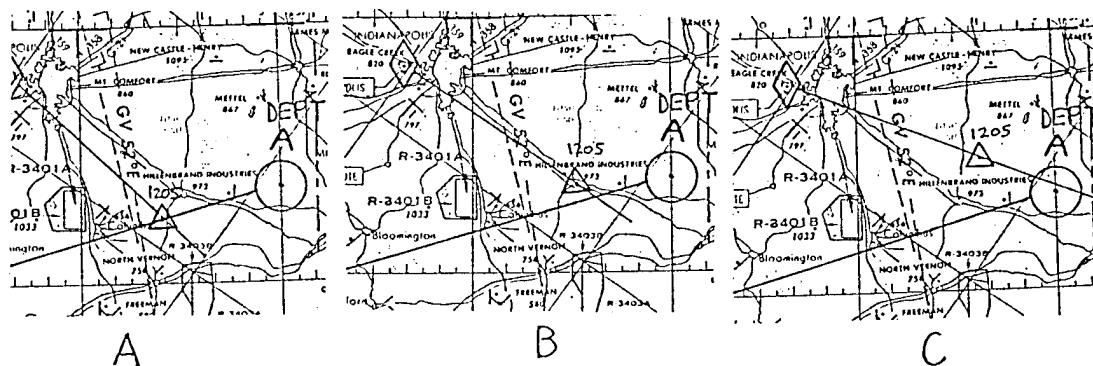
Aeronautical Knowledge Test #2

Choose the best answer. More than one answer per question may be correct.

1. Given the information shown in Figures 1. & 2., what heading should the pilot fly at the Departure Point?

- A. 268 degrees
- B. 266 degrees
- C. 256 degrees
- D. 254 degrees

2. Given the indications shown in Figure 2., which of the following most accurately depicts the aircraft's position? (Show your work on Figure 1.)



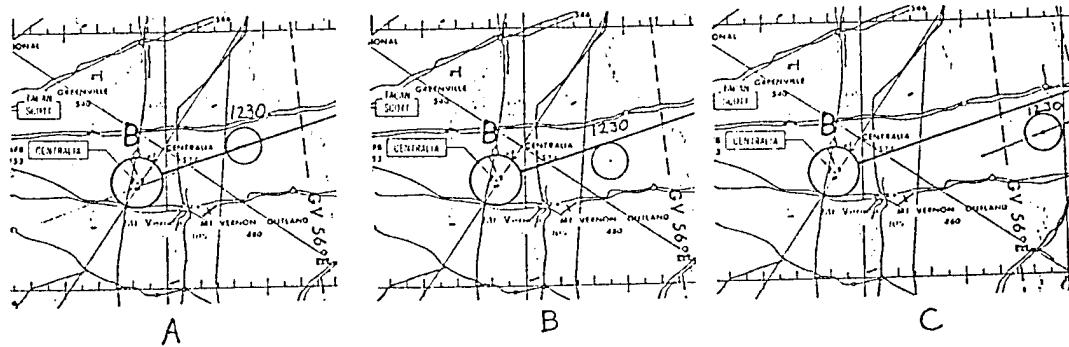
3. Based on the results of the fix resolved and plotted on Figure 1. and the indications in Figure 2., which magnetic heading should be flown to correct to course?

- A. 252 degrees
- B. 254 degrees
- C. 263 degrees
- D. 265 degrees

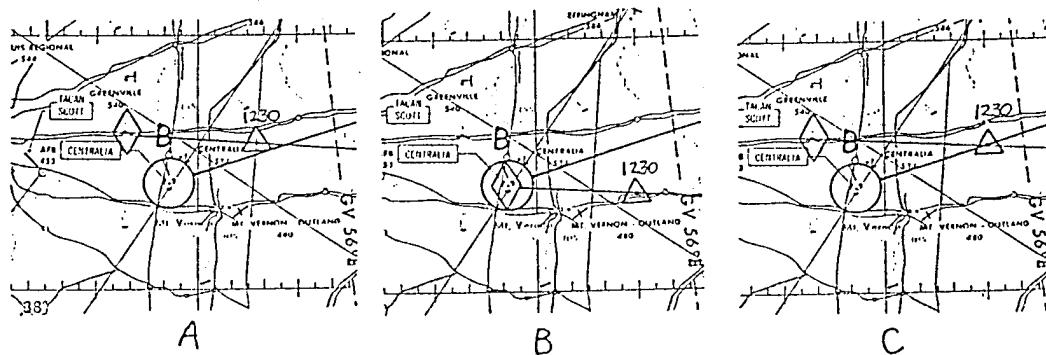
4. Using the information provided in Figure 3., which of the following is the most accurate ETA for Point B?

- A. 1235Z
- B. 1234Z
- C. 1217Z
- D. 1216Z

5. Using the indications shown in Figure 3., which of the following depictions most accurately represents where the aircraft will be at 1230Z?



6. Given the indications shown in Figure 4., which of the following most accurately depicts the aircraft's position at 1230Z?



7. Which of the following navigational facilities does not provide enough information to establish a fix?

- A. VOR
- B. VORTAC
- C. VOR/DME
- D. TAC

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- True Heading
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- Magnetic Heading

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- .6 NM

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- estimate of the aircraft's current position
- measurement of the aircraft's current position
- estimate of the aircraft's future position
- measurement of the aircraft's future position

15. A Fix is a(n)

- estimate of the aircraft's current position
- measurement of the aircraft's current position
- estimate of the aircraft's future position
- measurement of the aircraft's future position

16. If a pilot must fly a heading of 260 degrees to maintain a track of 270 degrees and now is 10 minutes earlier to the arrival gate than originally planned which general direction is the wind coming from?

- A. Northwest
- B. Northeast
- C. Southwest
- D. Southeast

17. To maintain a planned/desired ground track on a JNC chart, a pilot must correct for

- A. crosstrack error and precession
- B. drift and precession
- C. variation and precession
- D. variation and drift

18. What effect will a 25 knot headwind instead of a 50 knot headwind have on your Proposed ETA to your final destination?

- A. It will take only half as much time to get there
- B. It will take twice as much time to get there
- C. You will arrive later than originally planned
- D. You will arrive earlier than originally planned

19. The difference between Desired Course and Actual Course is called

- A. Variation
- B. Deviation
- C. Drift
- D. Slant Error

20. Variation is the difference between

- A. True North and True Heading
- B. True North and Magnetic North
- C. True Course and Magnetic Course
- D. subsequent readings of the same instrument

21. The distance between each tick mark on a line of longitude on a JNC chart

- A. equals 2 NM
- B. equals 5 NM
- C. equals 60 NM
- D. cannot be determined because they are not equidistant due to convergence

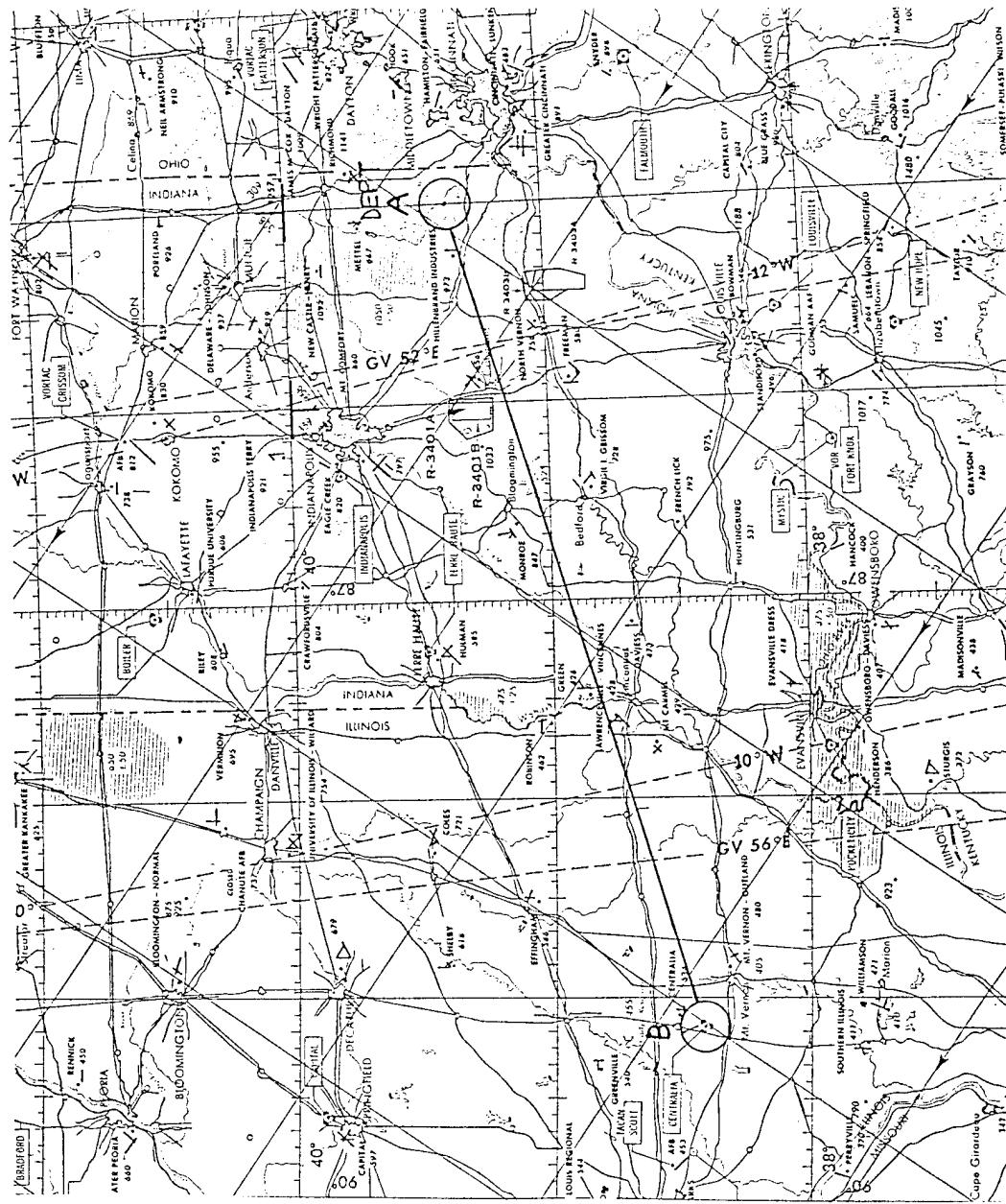


Figure 1. Chart Extract

Figure 2. TACAN Fix (CH 110)

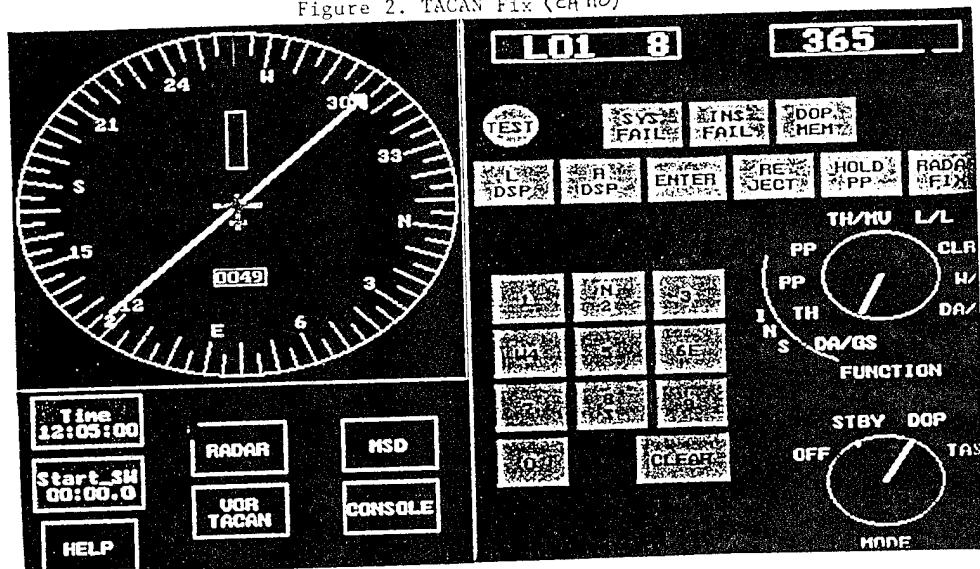


Figure 3. ETA and DR Information

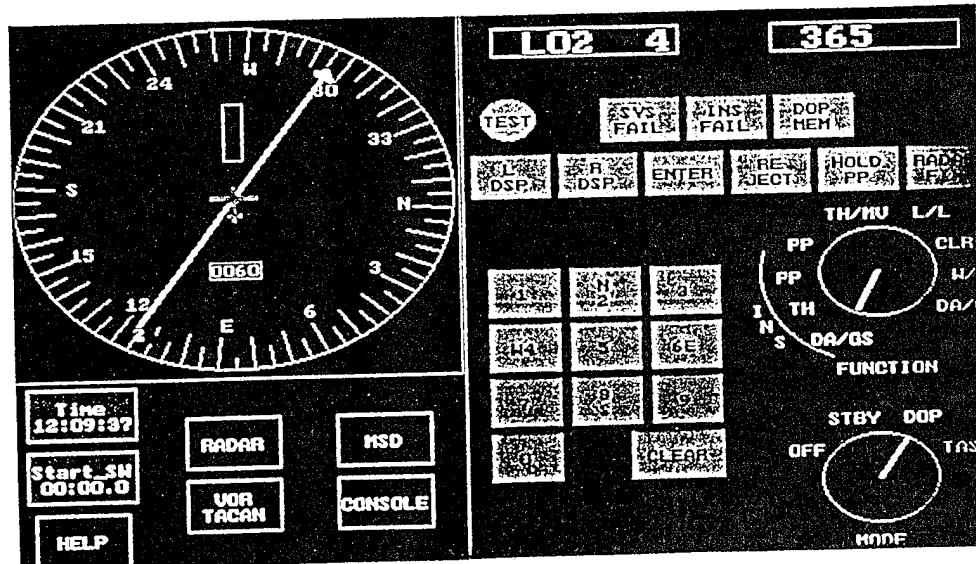
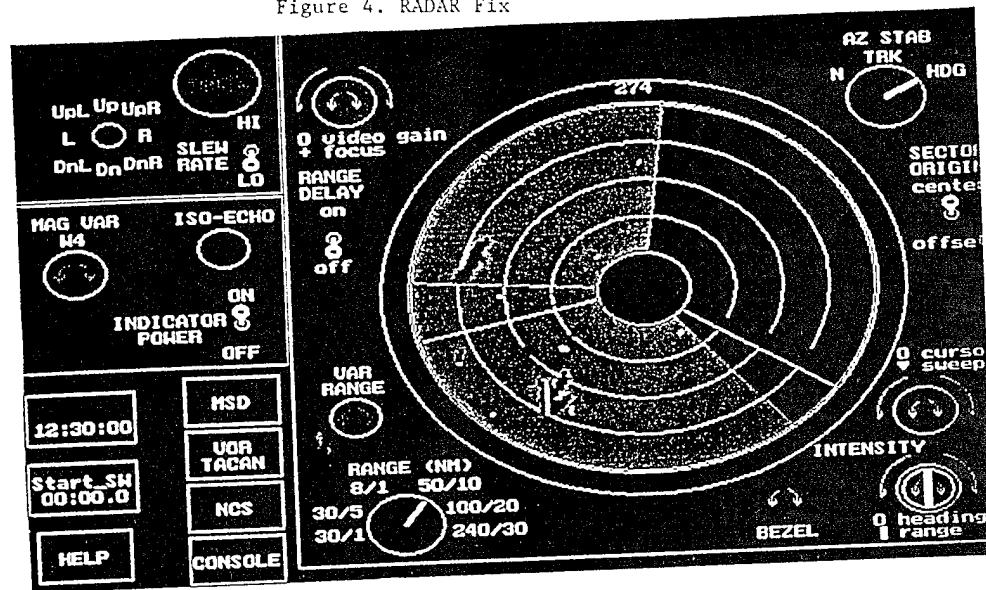


Figure 4. RADAR Fix



TC	MV	MC	DRIFT +L -R	HEADING TO FLY

TC TO NEXT POINT	VARIATION -E +W	MAGNETIC COURSE	DRIFT +L -R	MAGNETIC HEADING TO FLY

GROUND SPEED	HOW FAR TO NEXT POINT	HOW LONG TO NEXT POINT	TIME OF LAST FIX	ESTIMATED TIME OF ARRIVAL AT NEXT POINT

DR/FIX TIME ○	MAGNETIC HEADING	DRIFT -L +R	MAGNETIC COURSE	VARIATION +E -W	TC TO PLOT
TIME SINCE LAST FIX	GROUND SPEED	DISTANCE TO PLOT			

TAKING A RADAR FIX:

- RECORD TIME OF FIX

— 1 — BEARING AND RANGE TO PLOT ON CHART

DOD
FLIGHT INFORMATION PUBLICATION
(ENROUTE)



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DMA STOCK NO. ENRXUSIFRSP



EFF. DATE 94230

Supplemental Materials

APPENDIX F

STEM AND LEAF PLOTS OF STUDY DATA

POSTTEST

Valid cases: 147.0 Missing cases: .0 Percent missing: .0

Mean 58.8231 Std Err .9736 Min 24.0000 Skewness -.2573
Median 62.0000 Variance 139.3521 Max 90.0000 S E Skew .2000
5% Trim 59.0484 Std Dev 11.8047 Range 66.0000 Kurtosis -.0064
95% CI for Mean (56.8989, 60.7474) IQR 15.0000 S E Kurt .3975

Frequency Stem & Leaf

3.00 Extremes (24), (29)
6.00 3 . 888888
13.00 4 * 333333333333
12.00 4 . 888888888888
13.00 5 * 22222222222222
26.00 5 . 7777777777777777777777777777
28.00 6 * 222222222222222222222222222222
18.00 6 . 77777777777777777777
11.00 7 * 111111111111
13.00 7 . 66666666666666
3.00 8 * 111
1.00 Extremes (90)

Stem width: 10

Each leaf: 1 case(s)

POSTTEST

Statistic df Significance

K-S (Lilliefors) .0810 147 .0196

STEM AND LEAF PLOTS FOR MANCOVA (DEPENDENT VARIABLES)

CONGLOM

Valid cases: 147.0 Missing cases: .0 Percent missing: .0

Mean	2.2653	Std Err	.1249	Min	.0000	Skewness	.4160
Median	2.0000	Variance	2.2921	Max	6.0000	S E Skew	.2000
5% Trim	2.2090	Std Dev	1.5140	Range	6.0000	Kurtosis	-.3645
95% CI for Mean	(2.0185, 2.5121)			IQR	2.0000	S E Kurt	.3975

Frequency Stem & Leaf

Stem width: 1

Each leaf: 1 case(s)

INERT

Valid cases: 147.0 Missing cases: .0 Percent missing: .0

Mean	.4218	Std Err	.1012	Min	.0000	Skewness	5.5721
Median	.0000	Variance	1.5058	Max	11.0000	S E Skew	.2000
5% Trim	.2139	Std Dev	1.2271	Range	11.0000	Kurtosis	40.2612
95% CI for Mean	(.2217, .6218)			IQR	.0000	S E Kurt	.3975

Frequency Stem & Leaf

33.00 Extremes (1), (2), (4), (5), (11)

Stem width: 10

Each leaf: 3 case(s)

MISPLACE.

Valid cases: 147.0 Missing cases: .0 Percent missing: .0

Mean	1.3469	Std Err	.0758	Min	.0000	Skewness	.3804
Median	1.0000	Variance	.8446	Max	4.0000	S E Skew	.2000
5% Trim	1.3148	Std Dev	.9190	Range	4.0000	Kurtosis	-.1530
95% CI for Mean	(1.1971, 1.4967)			IQR	1.0000	S E Kurt	.3975

Frequency Stem & Leaf

Stem width: 1

Each leaf: 2 case(s)

NAIVE

Valid cases: 147.0 Missing cases: .0 Percent missing: .0

Mean	1.2585	Std Err	.0710	Min	.0000	Skewness	.1913
Median	1.0000	Variance	.7409	Max	3.0000	S E Skew	.2000
5% Trim	1.2317	Std Dev	.8608	Range	3.0000	Kurtosis	-.6212
95% CI for Mean	(1.1182, 1.3988)			IQR	1.0000	S E Kurt	.3975

Frequency Stem & Leaf

Stem width: 1

Each leaf: 2 case(s)

PARTIAL

Valid cases: 147.0 Missing cases: .0 Percent missing: .0

Mean	3.4014	Std Err	.1185	Min	1.0000	Skewness	.5168
Median	3.0000	Variance	2.0638	Max	9.0000	S E Skew	.2000
5% Trim	3.3677	Std Dev	1.4366	Range	8.0000	Kurtosis	.4754
95% CI for Mean	(3.1672, 3.6355)			IQR	2.0000	S E Kurt	.3975

Frequency Stem & Leaf

11.00	1 *	000000000000
.00	1 .	
31.00	2 *	000
.00	2 .	
41.00	3 *	00
.00	3 .	
31.00	4 *	00
.00	4 .	
21.00	5 *	00
.00	5 .	
11.00	6 *	000000000000
1.00	Extremes	(9.0)

Stem width: 1

Each leaf: 1 case(s)

APPENDIX G Consent Form

Note

This form is a privileged record and will be maintained within professional standards of confidentiality

Signing below indicates that the undersigned agrees to participate in the research study described. The participant is free to withdraw consent and discontinue participation at any time without prejudice or penalty of any kind.

Title: The Effect of Instructional Interaction/Coaching Strategies on the Construction of Fragile Knowledge in Flight Simulation

Purpose: To assess whether or not how a person is taught effects what they learn

Procedures: Pre-Study Data will be collected to provide background information on the study participants. This data will be used to provide possible explanations for the results obtained from the study. Two Aeronautical Knowledge Tests will be administered. The first test will provide a baseline on the participant's level of aeronautical knowledge prior to the simulation. The second test will measure knowledge gained by the simulation. An Inflight Evaluation will be given to measure the amount of knowledge that actually transferred from the training to the actual task. A post study questionnaire will be administered after the flight to collect data on the participant's perceptions of the research experience.

This study examines the effects of several common instructional interaction strategies. The specific instructional style the participant may see is not necessarily the instructor's preferred style or the participant's preferred style. Non optimal learning conditions may result. Friction with the instructor and frustration may be possible reactions. Nothing that happens in the study will effect or in any way influence the grade the participant receives for the class. Furthermore, goals, objectives, and content for the course have not been altered. Only the way the instruction is delivered has been changed. All events will be critiqued to 100% to ensure fairness to participants and non-participants.

At no time will any data, results, conclusions, or discussion ever be attributed to the specific participant! Names or any other unique identifiers will not be used outside of participant/researcher interaction.

Any questions regarding the research can be directed to Michael Mullas both during or after the study has been completed at 472-0845 or E-mail at the following Internet address: MULLASMW@34TRWMAIL.USAFA.AF.MIL or in person. Questions concerning your rights as a participant can be directed to: Office of Sponsored Programs, CU-Denver, Campus Box 123, P.O. Box 173364, Denver, CO 80217-3364, telephone (303) 556-2770.

Signature

Date

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